KMI/NITEP School

Dark Matter

From Ultra Light to Super Massive

March 9-11, 2026

KMI Science Symposia (ES635), Nagoya University

Lecture 4-1

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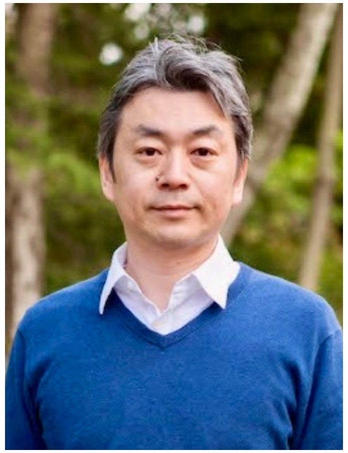
Who am I?



> 25 years DM hunter

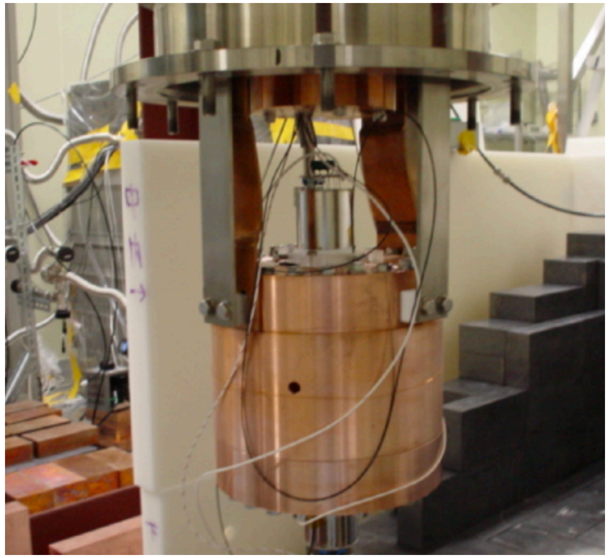
Masaki Yamashita

Start from **Oct 2025** at Nagoya

Experimental Astroparticle Physicst
Dark Matter, Neutrino ++

- XENON (now)
- XLZD (future)
- Hyper Kamiokande (coming soon)

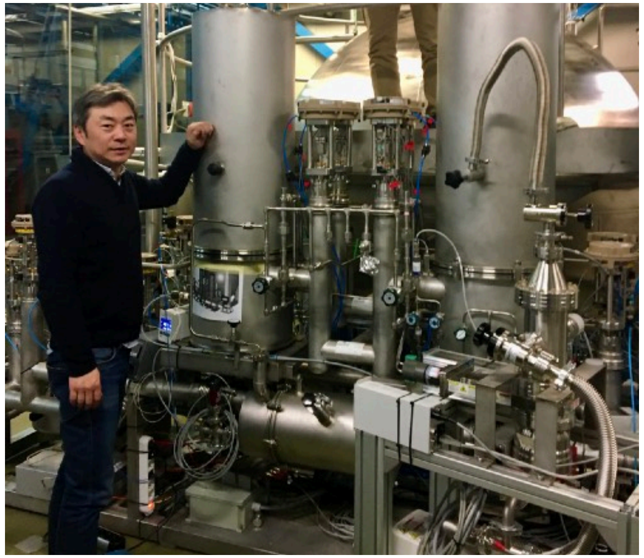
2000 ~ @Kamioka
Ph.D at Waseda



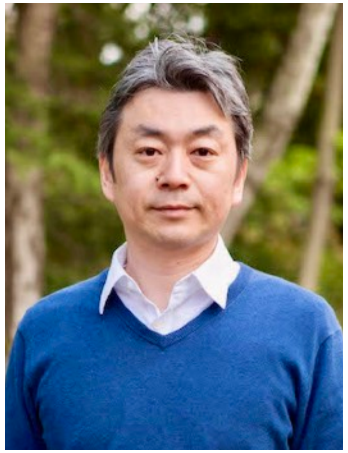
2003~ XENON10@Gran Sasso
Postdocs at Columbia

2008~ XMASS@Kamioka UTokyo

2019~ XENON@Gran Sasso



Who am I?



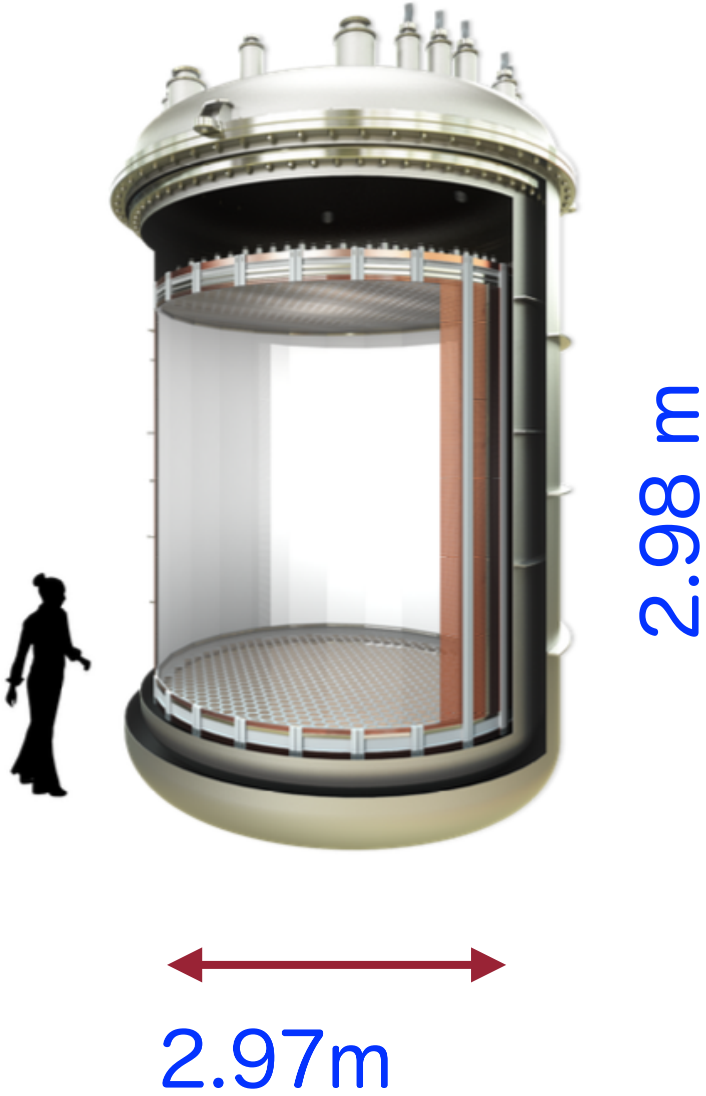
Masaki Yamashita (山下　雅樹)

Start from **2025/Oct/1st** at Nagoya

Until then, Kavli IPMU, UTokyo
at Kamioka

Experimental Astroparticle Physicst
Dark Matter, Neutrino ++
・XENON (now)
・XLZD (future)
・Hyper Kamiokande (coming soon)

XLZD
DM direct search
Double Beta Decay



Hyper Kamiokande

D = 69m, H = 94m

Contents

Lecture 1

Physics of Dark Matter Direct Detection

1. Motivation/Evidence of Dark Matter
2. Dark Matter Candidates and WIMPs
3. Why WIMP?
4. Experimental Search for WIMPs

Lecture 2

1. WIMP Direct Detection
2. Background sources
3. Detection technologies
4. Liquid xenon time projection chamber
5. Current experiments
6. Future experiments
7. Summary and outlook

Evidence of Dark Matter(recap)

- Cluster dynamics
- Flat rotation curves
- Gravitational lensing
- BAO and galaxy clustering
- CMB peak structure
- Bullet Cluster
- Structure formation history

Evidence of Dark Matter

- **Cluster dynamics**
- Flat rotation curves
- Gravitational lensing
- BAO and galaxy clustering
- CMB peak structure
- Bullet Cluster
- Structure formation history

・Galaxies in clusters move at extremely high velocities.
・**The visible mass is far too small to gravitationally bind the system.**

↓

Clusters require several times more mass than what we see.
(**1933, Zwicky**)

Coma cluster by IR & visible light

Evidence of Dark Matter

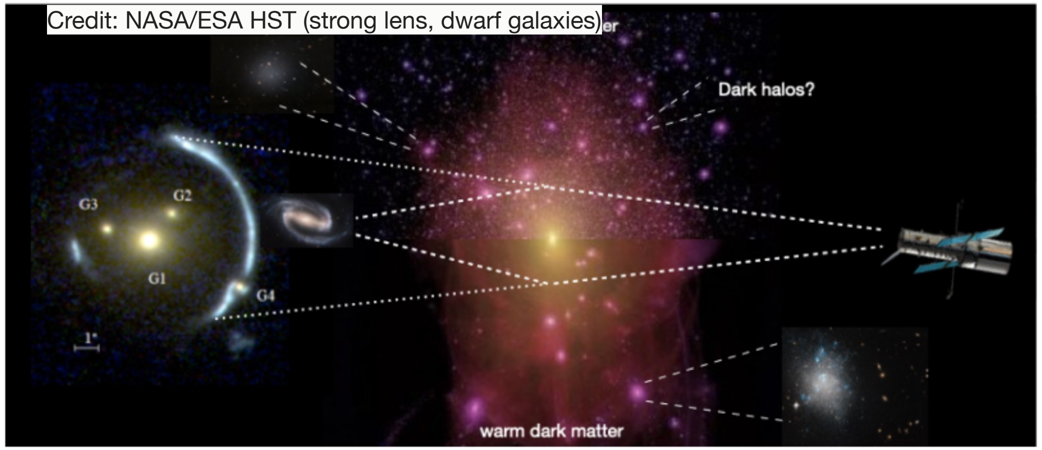
- Cluster dynamics
- **Flat rotation curves**
- Gravitational lensing
- BAO and galaxy clustering
- CMB peak structure
- Bullet Cluster
- Structure formation history

Stars in galaxies rotate too fast at large radii. The rotation curves remain flat, even where visible matter becomes scarce.
To keep the stars gravitationally bound, a large amount of unseen mass is required.

⬇

Dark matter halos around galaxies.

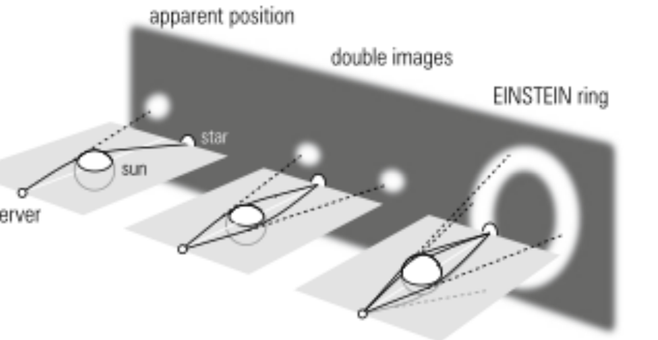
Evidence of Dark Matter

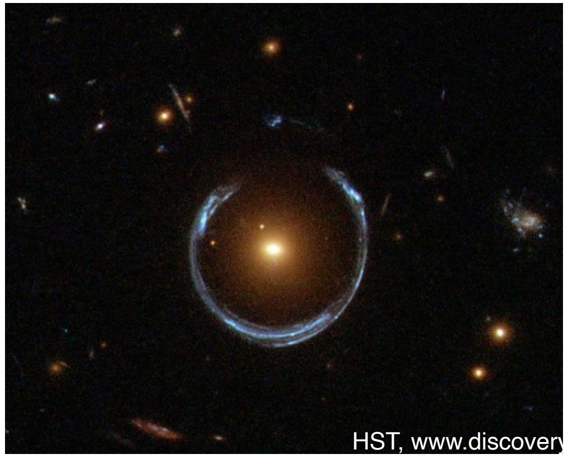


oint to a massive, invisible component:

- **Gravitational lensing**
- BAO and galaxy clustering

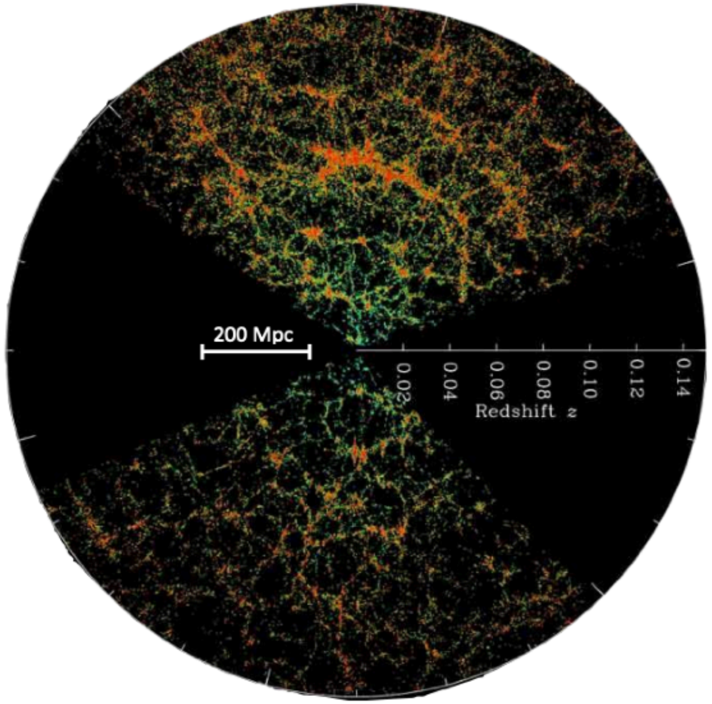
Strong and weak lensing of background galaxies reveal mass distributions much larger than the visible component.
The lensing strength often cannot be explained without additional, invisible mass.





→ Gravity indicates more mass than luminous matter.

nce of Dark Matter

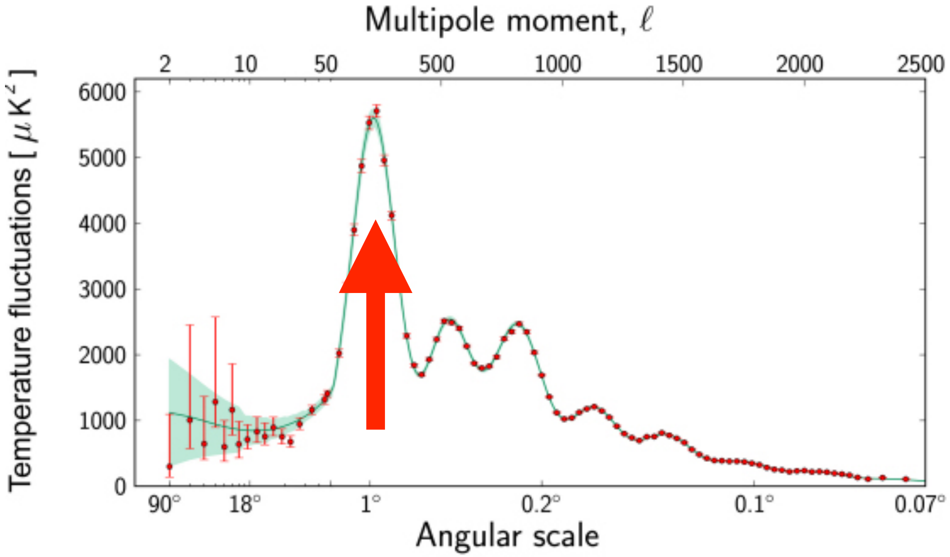


- **BAO and galaxy clustering**
- CMB peak structure
- Bullet Cluster
- Structure formation history

The galaxy power spectrum and the **“standard ruler”** of BAO are in excellent agreement with cosmological models that include cold dark matter (CDM).

→ The growth of cosmic structure requires dark matter.

Evidence of Dark Matter

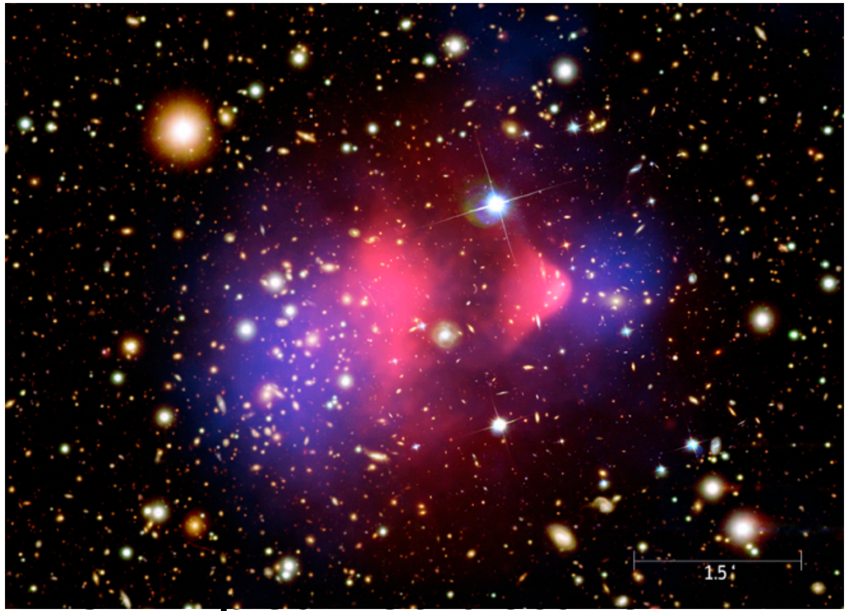


- **CMB peak structure**
- Bullet Cluster
- Structure formation history

The heights and positions of acoustic peaks, especially the third peak and beyond, strongly depend on the amount of dark matter.
WMAP and Planck measurements match ΛCDM predictions with high precision.
→ CMB demands a specific dark matter density ($\Omega_c h^2$).

Evidence of Dark Matter

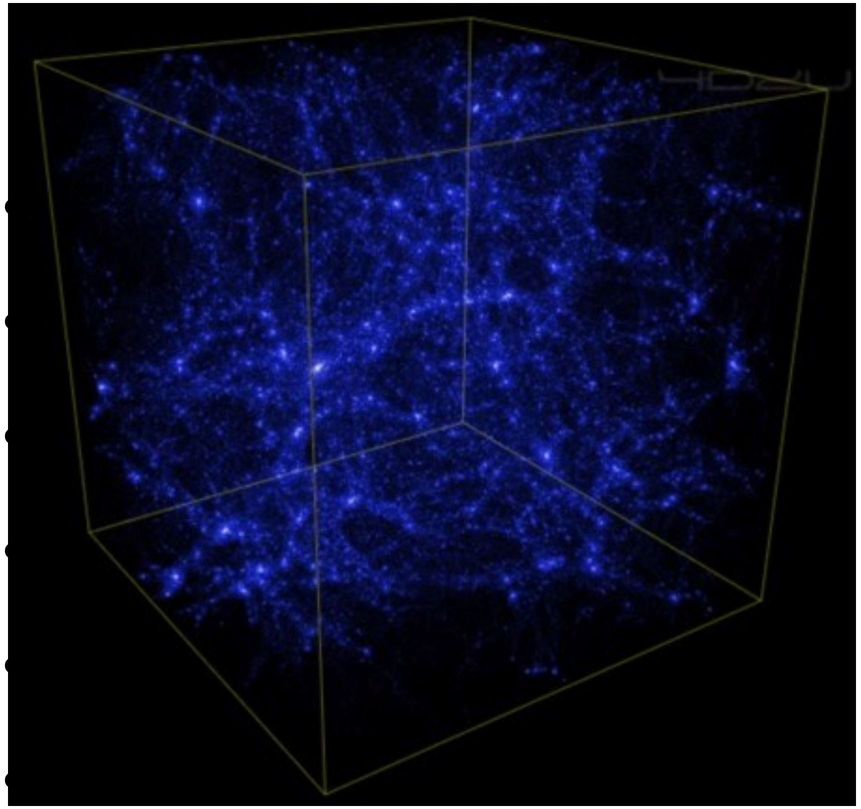
Independent observations all point to a massive, invisible component:



- **Bullet Cluster**
- Structure formation history

In a collision of two galaxy clusters:
-Hot gas (baryons) slows down and remains in the middle.
-The gravitational potential, traced by lensing, passes through with the galaxies.
Visible matter and gravitational mass separate.
→ Hard to explain with modified gravity; requires non-collisional dark matter.

Evidence of Dark Matter



- **Structure formation history**

In the early Universe, baryons were tightly coupled to photons and could not grow density fluctuations.
Dark matter, being non-interacting with radiation, **grows early and seeds structure.**

→ Galaxies could not form without dark matter.

Die Rotverschiebung von extragalaktischen Nebeln

von F. Zwicky.

(16. II. 33.)

Inhaltsangabe. Diese Arbeit gibt eine Darstellung der wesentlichsten Merkmale extragalaktischer Nebel, sowie der Methoden, welche zur Erforschung derselben gedient haben. Insbesondere wird die sog. Rotverschiebung extragalaktischer Nebel eingehend diskutiert. Verschiedene Theorien, welche zur Erklärung dieses wichtigen Phänomens aufgestellt worden sind, werden kurz besprochen. Schliesslich wird angedeutet, inwiefern die Rotverschiebung für das Studium der durchdringenden Strahlung von Wichtigkeit zu werden verspricht.

Rotverschiebung extragalaktischer Nebel. 125

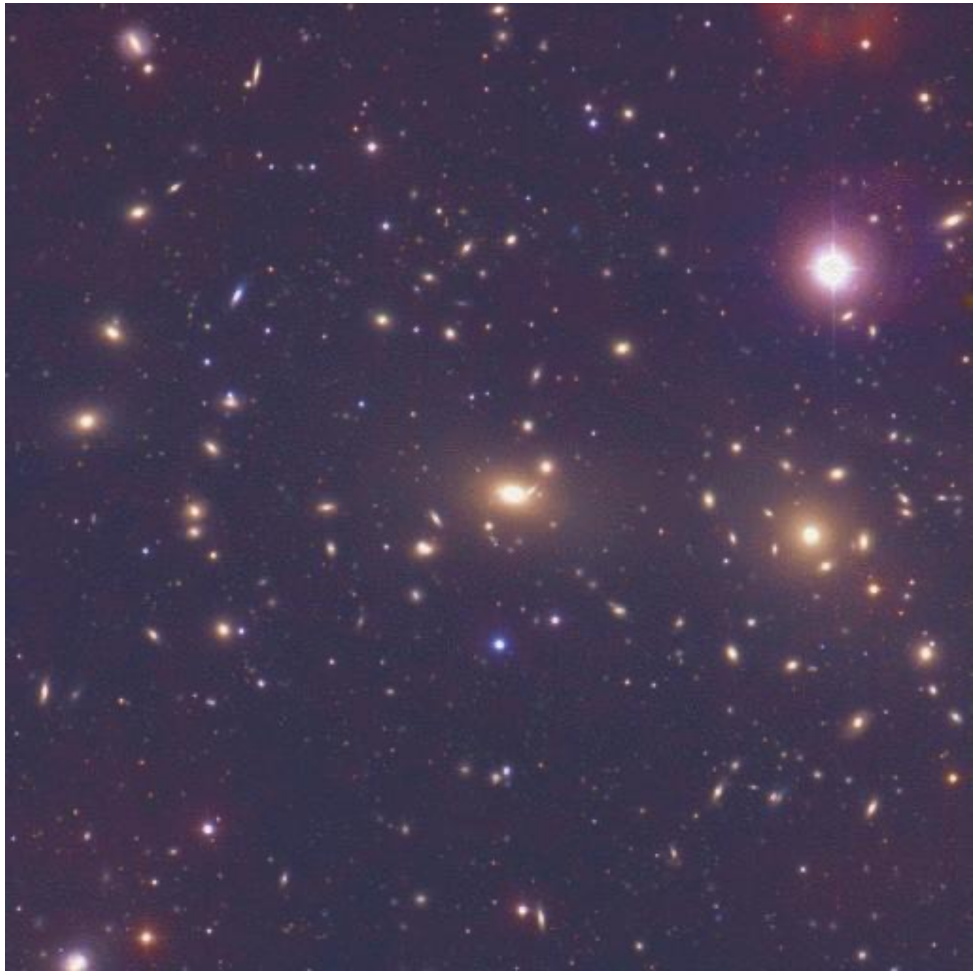
Um, wie beobachtet, einen mittleren Dopplereffekt von 1000 km/sek oder mehr zu erhalten, müsste also die mittlere Dichte im Comasystem mindestens 400 mal grösser sein als die auf Grund von Beobachtungen an leuchtender Materie abgeleitete[1]). Falls sich dies bewahrheiten sollte, würde sich also das überraschende Resultat ergeben, dass dunkle Materie in sehr viel grösserer Dichte vorhanden ist als leuchtende Materie.

translated version 1711.01693

In order to obtain, as observed, a medium-sized Doppler effect of 1000 km/s or more, the average density in the Coma system would have to be at least 400 times greater than that derived on the basis of observations of luminous matter [This would be in approximate accordance with the opinion of Einstein and de Sitter as discussed in Sect. 4.]. If this should be verified, it would lead to the surprising result that dark matter exists in much greater density than luminous matter.

Coma cluster

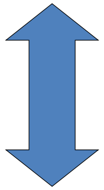
http://hubblesite.org/copyright/ © NASA/STScl



Coma cluster by IR & visible light

- Zwicky started by estimating the total mass of Coma
- 800 galaxies x 10^9 solar masses, as suggested by Hubble.
- An estimate for the physical size of the system, 10^6 light-years,
- He calculated the average kinetic energy and finally a velocity dispersion.

80km/s



the observed **velocity** dispersion
1500 ~ 2000km/s

Practice: The velocity dispersion of galaxies within a galaxy cluster

Virial Theorem

$$\frac{1}{2}\ddot{I} = 2T + \Phi$$

Virial: $I = \sum_i \mathbf{r}_i \cdot \mathbf{p}_i$

mi: i_{th} Galaxies's mass

r_i: the distance of the i-th galaxy from the center of the cluster

$\ddot{I} = 0$

Equilibrium state (it does not change with time)

T: Total energy

$T = \frac{1}{2} M\sigma^2$

M: total mass of cluster

σ: velocity dispersion

Φ: gravitational potential

$\Phi = -\frac{GM^2}{fR}$ R: cluster's radius

f: constant (~2)

$\sigma^2 = \frac{GM}{fR}$ → σ ?

Number of galaxies: 800、average $10^9\ M_\odot$

-> $8 \times 10^{11}\ M_\odot$

$R = 300\,kpc$

$G = 6.67 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$

Answer

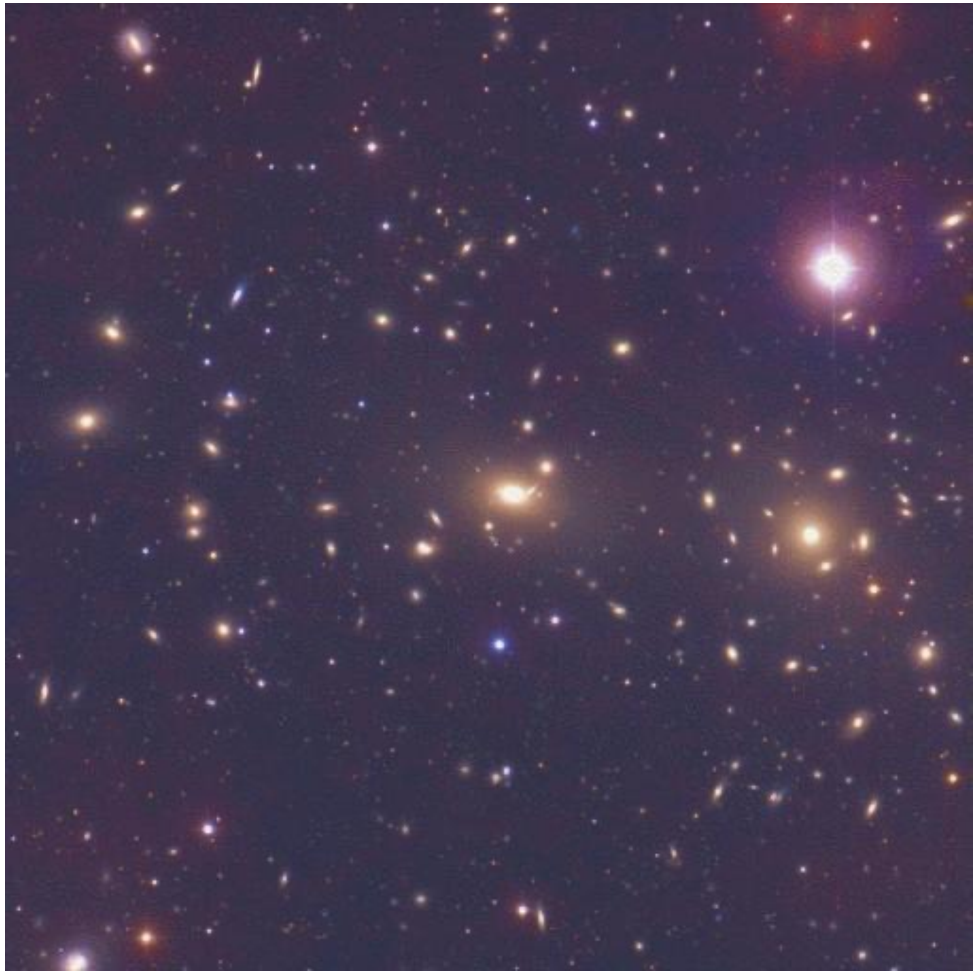
- $$\sigma^2 = \frac{6.67 \times 10^{-11}\ m^3 kg^{-1}\ s^{-2} \times 8 \times 10^{11} \times 2.0 \times 10^{30} kg}{2 \times 300 \times 10^3 \times 3.1 \times 10^{16}\ m}$$

$$= 5.34 \times 10^9\ (m/s)^2$$

$$\sigma = 75.7\ km/s$$

$\Longleftrightarrow$ $\sigma = 1500 \sim 2000 km/sec$

Coma cluster



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80km/s

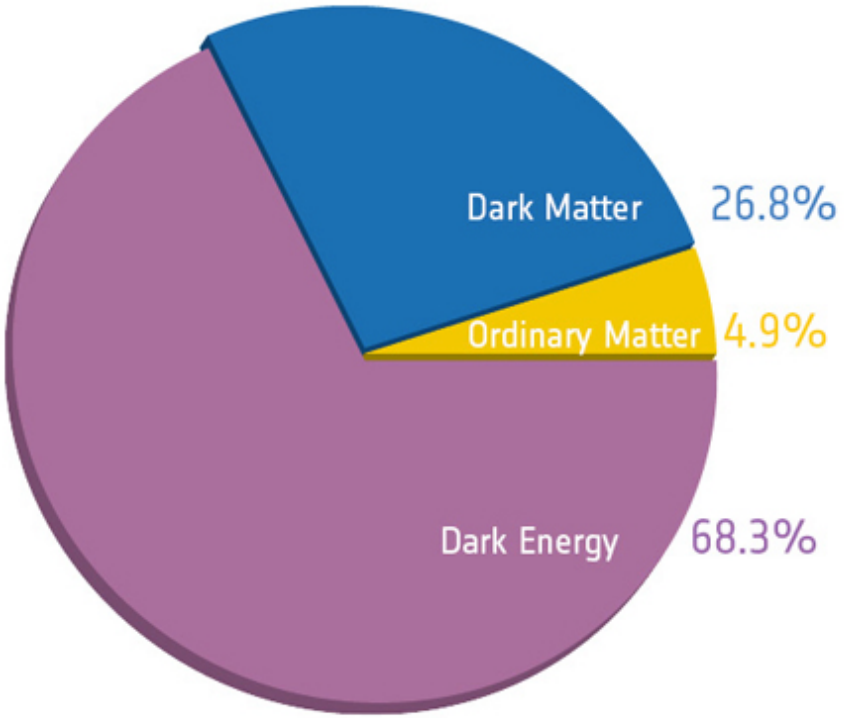
↕

the observed **velocity** dispersion

1500km/s

× hundreds of times larger than the total mass is required

Summary of CMB observation



<u>A lot of information!</u>

Snapshot of the early universe (380,000 years old)

Age of the universe 13.8 Billion years old

Curvature (Ω ~1) -> Flat

etc etc

- - - *Planck* 2018 6-parameter fit to flat ΛCDM cosmology -

baryon density of the Universe	$\Omega_b = \rho_b/\rho_{crit}$	‡ $0.02237(15)\,h^{-2}$ = † $0.0493(6)$
cold dark matter density of the Universe	$\Omega_c = \rho_c/\rho_{crit}$	‡ $0.1200(12)\,h^{-2}$ = † $0.265(7)$
100 × approx to r_*/D_A	$100 \times \theta_{MC}$	‡ $1.04092(31)$
reionization optical depth	τ	‡ $0.054(7)$
ln(power prim. curv. pert.) ($k_0 = 0.05\,\mathrm{Mpc}^{-1}$)	$\ln(10^{10}\Delta^2_{\mathcal{R}})$	‡ $3.044(14)$
scalar spectral index	n_s	‡ $0.965(4)$
pressureless matter parameter	$\Omega_m = \Omega_c + \Omega_b$	† $0.315(7)$
dark energy density parameter	Ω_Λ	† $0.685(7)$
energy density of dark energy	ρ_Λ	† $5.83(16) \times 10^{-30}\,\mathrm{g\,cm}^{-3}$
cosmological constant	Λ	† $1.088(30) \times 10^{-56}\,\mathrm{cm}^{-2}$
fluctuation amplitude at $8\,h^{-1}$ Mpc scale	σ_8	† $0.811(6)$

Summary: evidences at variety scales

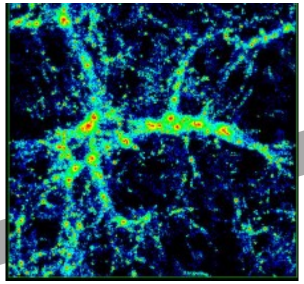
10^{23} cm

10^{25} cm

10^{26} cm

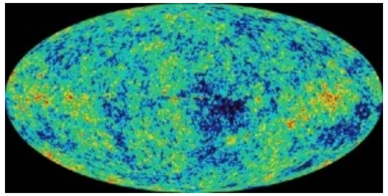
10^{28} cm

Large Scale structure



bullet cluster

CMB



DM Map

galaxy cluster

galaxy rotational speed

What is Dark Matter?

Possible Properties of Dark Matter

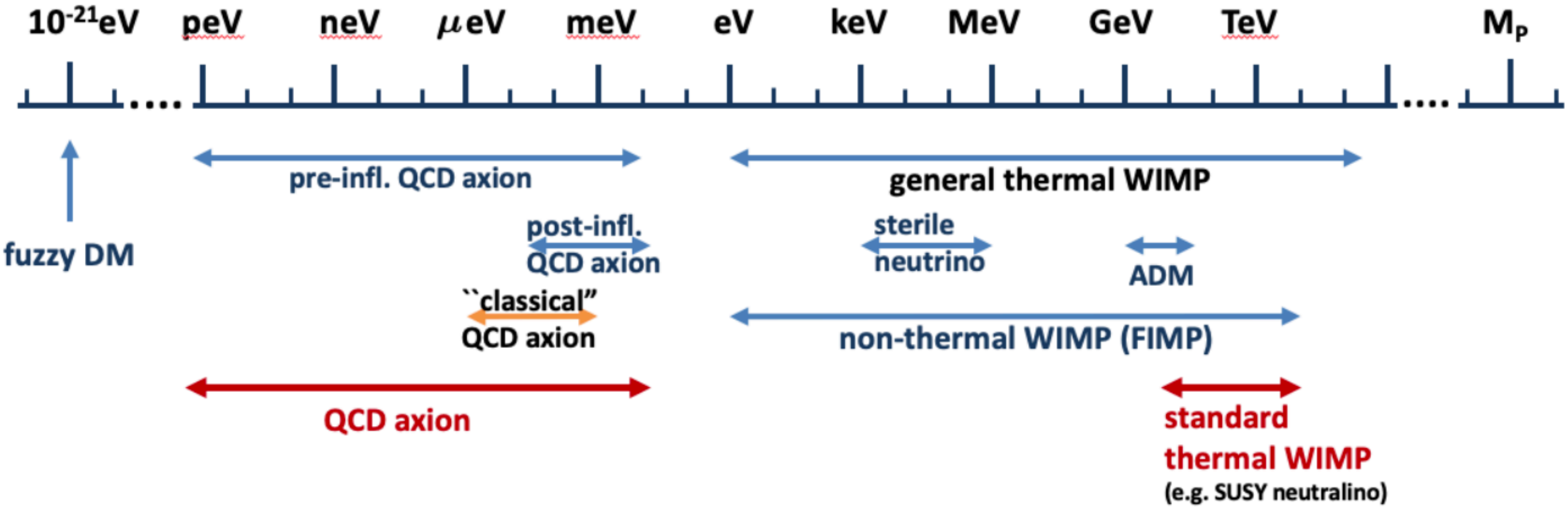
- **Gravitationally interacting**
  - Revealed through gravitational effects (rotation curves, lensing, structure formation)
- **Stable or very long-lived**
  - Lifetime longer than the age of the Universe
- **Non-baryonic**
  - Not composed of protons or neutrons (BBN & CMB constraints)
- **Cold (or at most warm)**
  - Non-relativistic at the time of structure formation
- **Electrically neutral, Non-luminous**
  - No electric charge, does not emit, absorb, or reflect electromagnetic radiation
- **Not in Standard Model Particles**
  - New Particle?

important for not only cosmology but also particle physics

DM candidates

- **Baryonic Dark Matter**
  - Big Bang Nucleosynthesis
  - Massive Compact Halo Object (MACHO)
- **Non-Baryonic Dark Matter**
  - Primordial Black Hole (PBH)
  - neutrino
  - Axion
  - **Weakly Interacting Massive Particle (WIMP)**

Dark Matter Mass

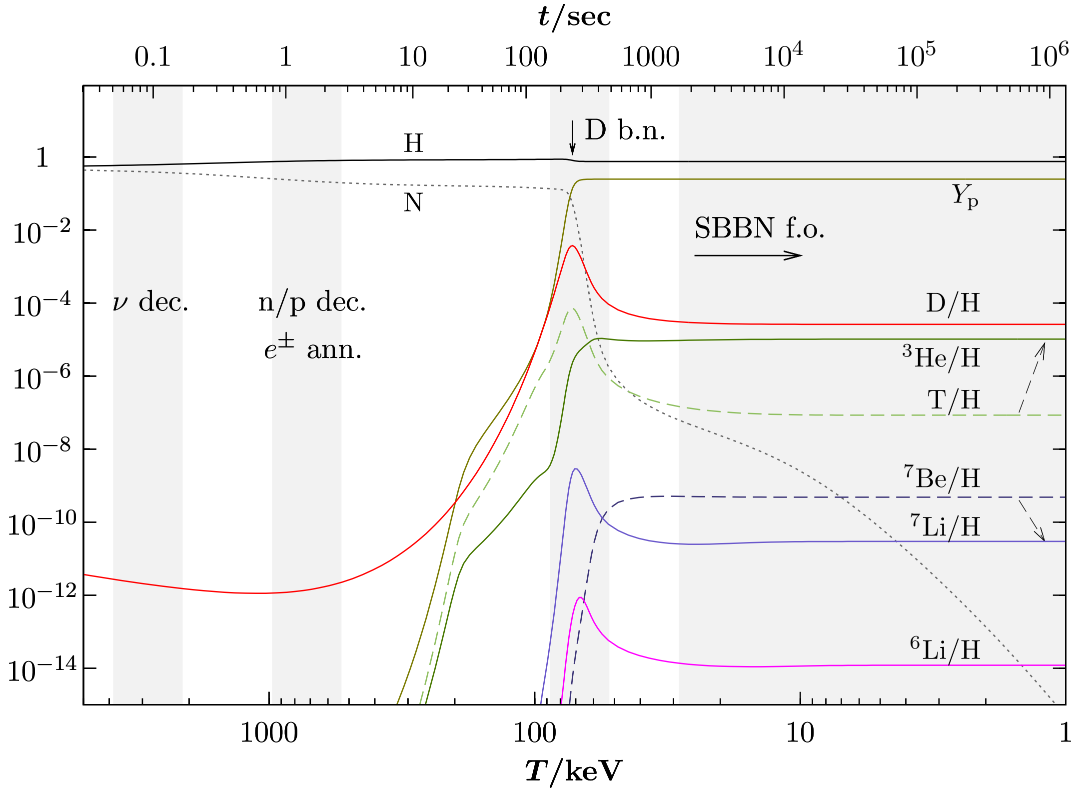


Why WIMP?

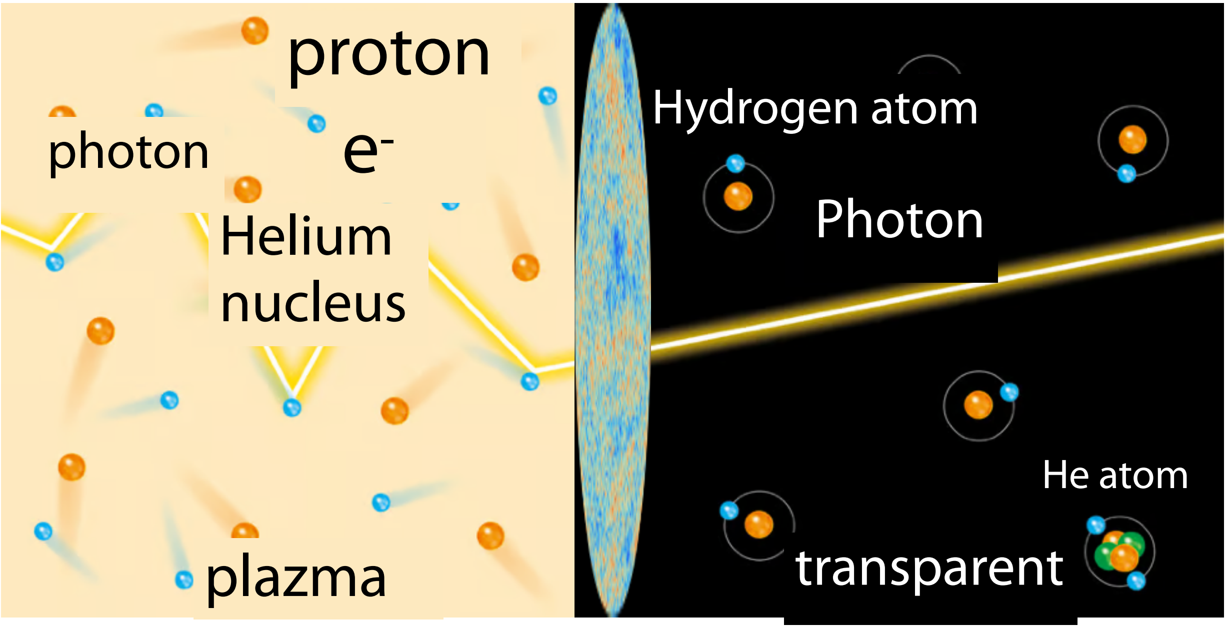
- WIMPs are thermally produced.
- WIMPs arise naturally in models of new physics.
  - (e.g. SUSY → the neutralino),
- WIMPs can be probed through multiple observational approaches:
  - collider searches
  - direct detection
  - indirect detection

Success of 'Freeze out' mechanism

Big Bang Nucleosynthesis (BBN)



CMB



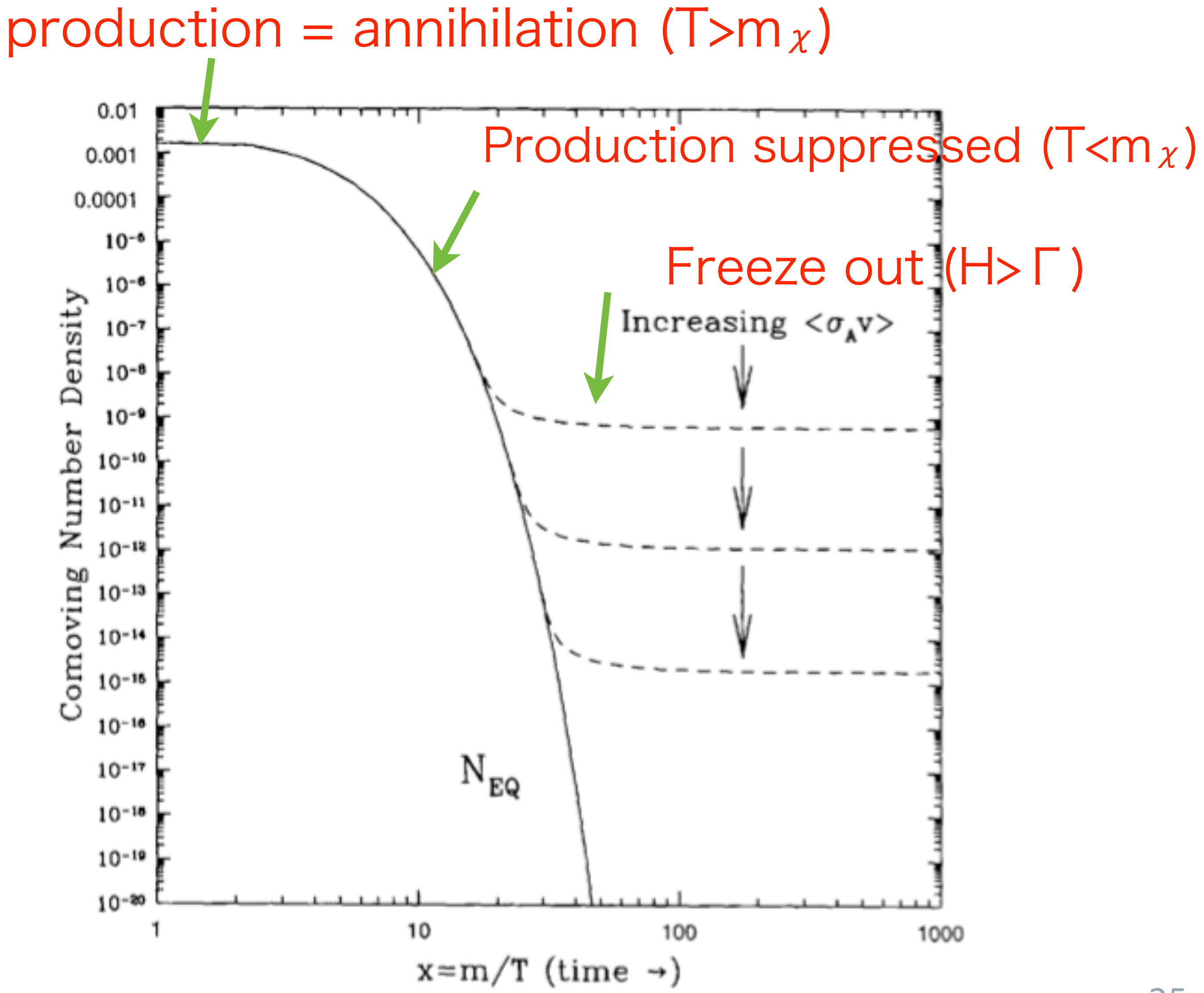
The relic abundances of many particles are fixed by freeze-out or decoupling during the thermal evolution of the Universe. Why not for DM? -> WIMP

Freeze out

Assuming neutral, massive and only weakly interacting particle (WIMP) in the early universe.

- H:expansion rate
- Γ: interaction rate
  - **(1) T>$m_χ$ (equilibrium)**
    - χχ ⇄ ff′ (f:SM particle)
  - **(2) T<$m_χ$ (decouple)**
    - χχ → ff′
  - **(3) H>Γ**
    - freeze out

G. Jungman et al Phys. Rep. 267 (1996)



WIMP Miracle

Boltzmann Eq.

$$\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle \left(n^2 - n_{\rm eq}^2\right), \qquad H \equiv \frac{\dot{a}(t)}{a(t)}.$$

$$n_{\rm eq} \simeq \left(\frac{mT}{2\pi}\right)^{3/2} \exp\left(-\frac{m}{T}\right)$$

See detail in G. Jungman, et al. Phys. Rep. 267 (1996) 195

H ~ Γ: numerical solution provides:

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c}$$
$$\simeq 0.1 \left(\frac{10^{-26}{\rm cm}^3/{\rm s}}{<\sigma v>}\right)$$
$$\simeq 0.1 \left(\frac{0.01}{\alpha}\right)^2 \left(\frac{m_\chi}{100{\rm GeV}}\right)^2$$

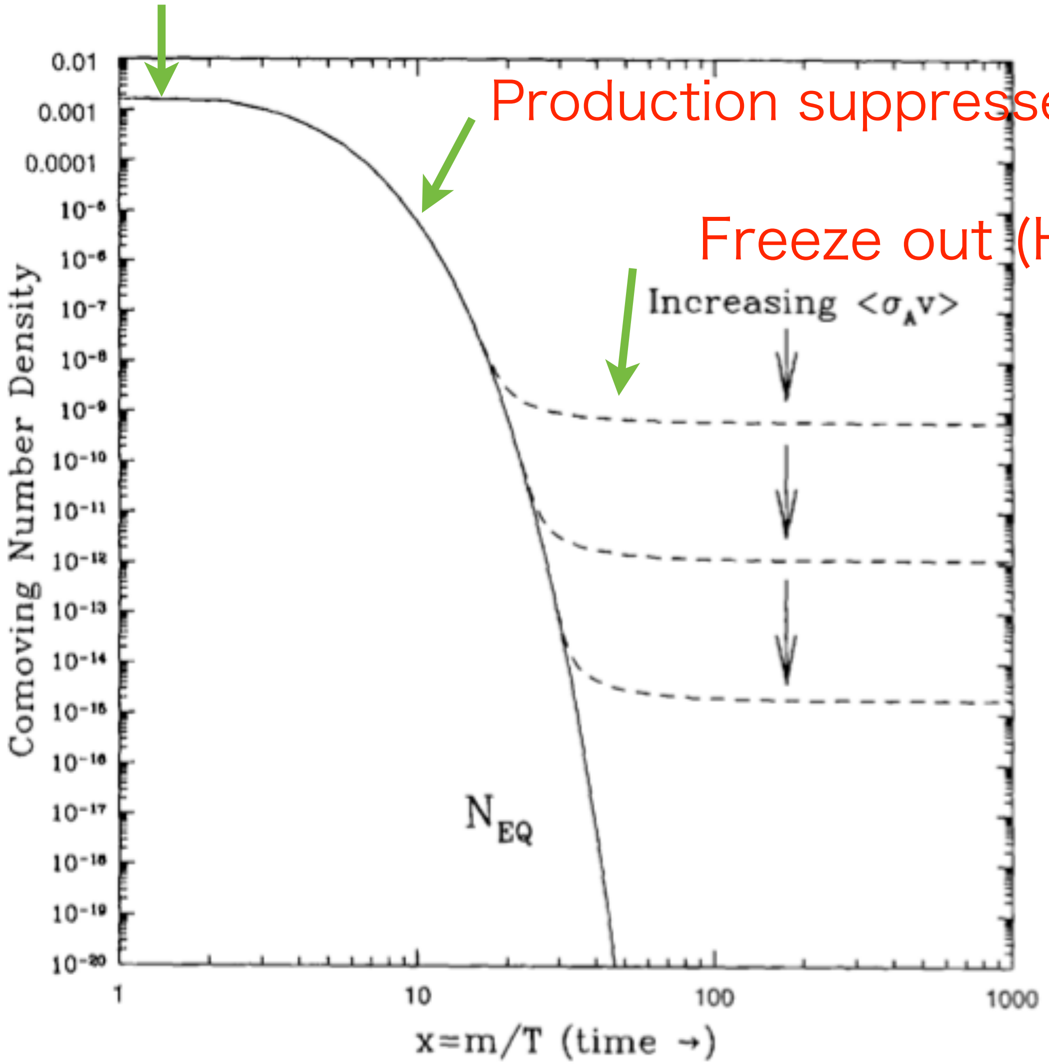
CMB: $\Omega_\chi h^2 \sim 0.12$

G. Jungman et al Phys. Rep. 267 (1996)

production = annihilation (T>m_χ)

Production suppressed (T<m_χ)

Freeze out (H>Γ)



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  - indirect detection

Supersymmetric Particles

Each particle in the Standard Model acquires a corresponding supersymmetric partner.

fermion -> boson or boson -> fermion

ex: higgs -> higgsino , neutrino->sneutrino (spin 1/2 difference)

- **R-parity**

→ R = $(-1)^{3B+L+2S}$, B = baryon number, L = lepton number

R = 1 for SM particles

R = -1 for SUSY

- **DM candidate**

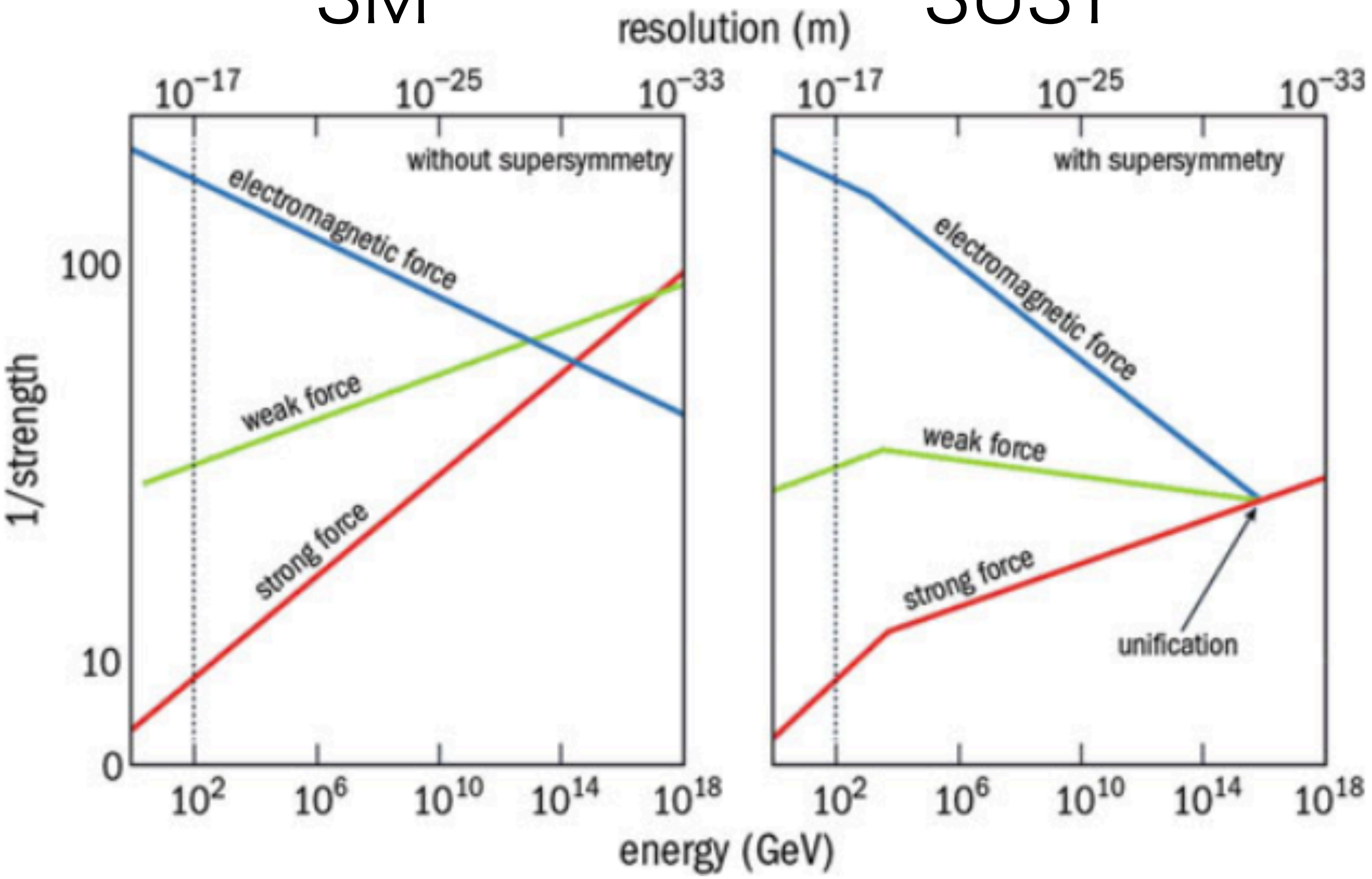
The lightest (and therefore stable) supersymmetric particle is a dark matter candidate.

=> Neutralino

Why SUSY?

- **Stabilizing the electroweak scale:**
  - SUSY addresses the hierarchy problem by canceling large quantum corrections to the Higgs mass.
- **Providing a dark matter candidate:**
  - With conserved R-parity, the lightest supersymmetric particle (LSP) is stable and naturally serves as a dark matter candidate.
- **Gauge coupling unification:**
  - In SUSY extensions of the Standard Model, the three gauge couplings unify at a high energy scale.

SM SUSY



Alessandro De AngelisMário Pimenta
Introduction to Particle and Astroparticle Physics, Springer

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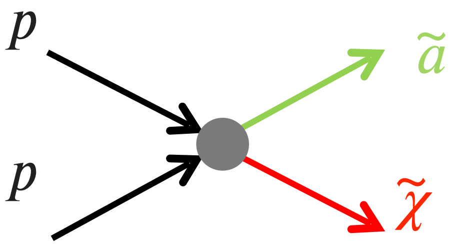
Let’s look for WIMPs.

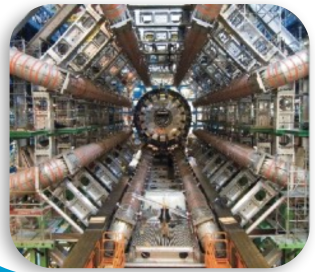
Experimental Search for WIMPs

Generation at accelerators e.g. LHC

$$p + p \rightarrow \ldots \rightarrow \ldots + \tilde{a} + \tilde{\chi}$$



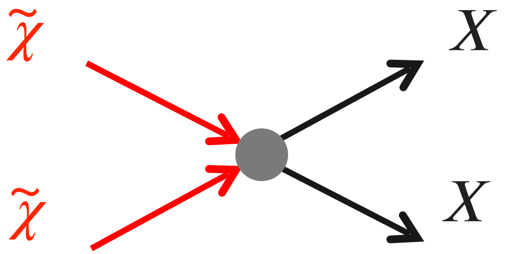
- indirect detection by missing mass + momentum
- a signal would not yet be a direct proof for the missing Dark Matter of the universe



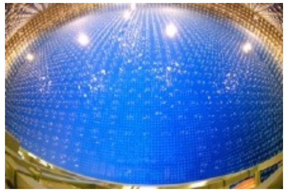
WIMP annihilation in the universe

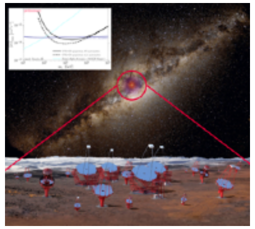
$$\tilde{\chi} + \tilde{\chi} \rightarrow \ldots \rightarrow \ldots + \upsilon + \tilde{\upsilon} \;,\; \ldots \gamma + \gamma$$

$$\ldots \rightarrow \ldots + e^{+}, \ldots + \bar{p}$$



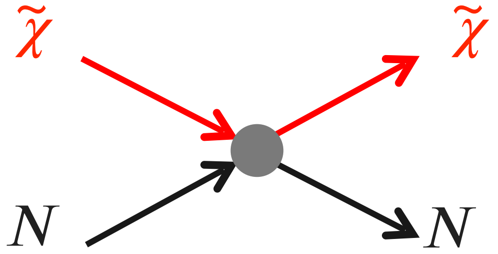
- search for neutrinos or gammas from large mass accumulations (center of galaxy, sun,…)





Direct WIMP nucleus scattering

$$\tilde{\chi} + N \rightarrow \tilde{\chi} + N$$

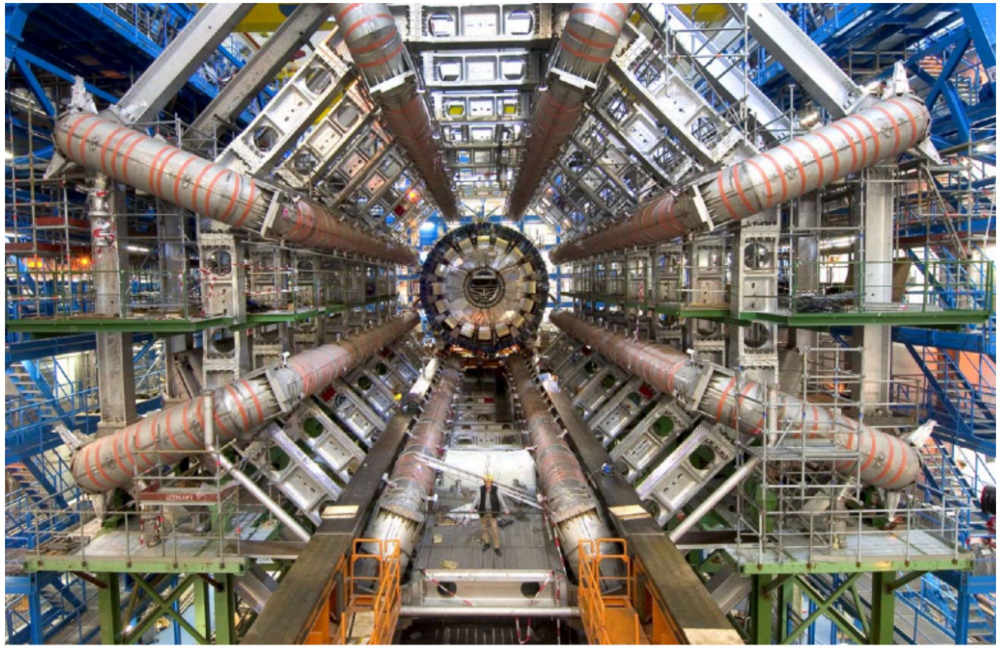


- direct proof for WIMPs in halo of our galaxy
- ultra low momentum transfer and rate

WIMP Dark Matter Searches (Collider)

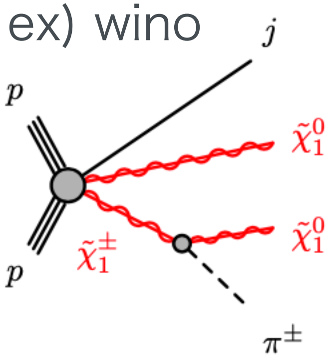
Collider (LHC)

ATLAS-CONF-2021-015

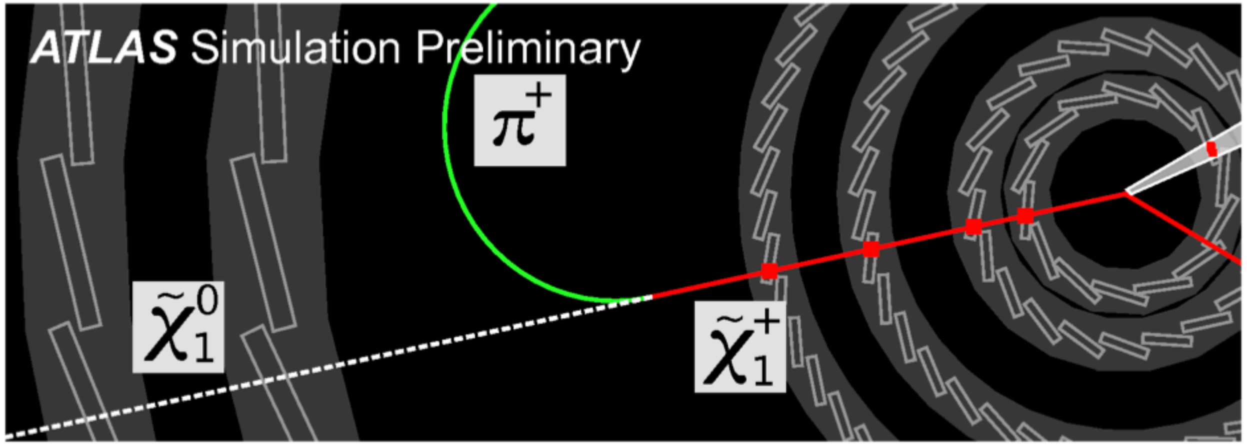


If a SUSY particle that is a dark matter candidate is produced, it escapes the detector without being detected;
therefore, we search for the missing energy it carries away.

ex) wino

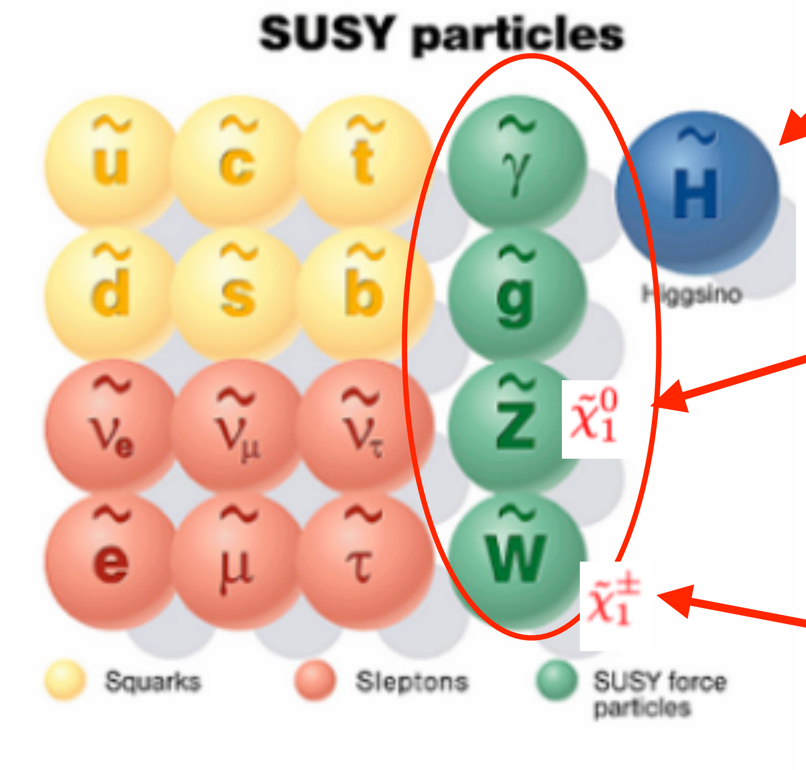


(a) $pp \to \tilde{\chi}_1^\pm \tilde{\chi}_1^0 j$



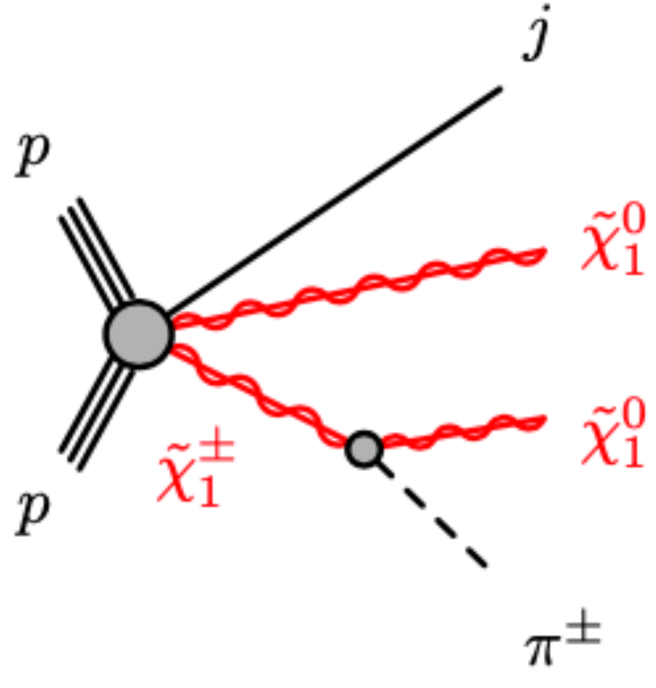
Pure wino/Pure Higgsino

e.g. Hisano+ JHEP06(2015)097



Higgsino < 1 TeV

Wino < 3 TeV



(a) $pp \to \tilde{\chi}_1^\pm \tilde{\chi}_1^0 j$

Small mass difference btw Chargino and Neutralino

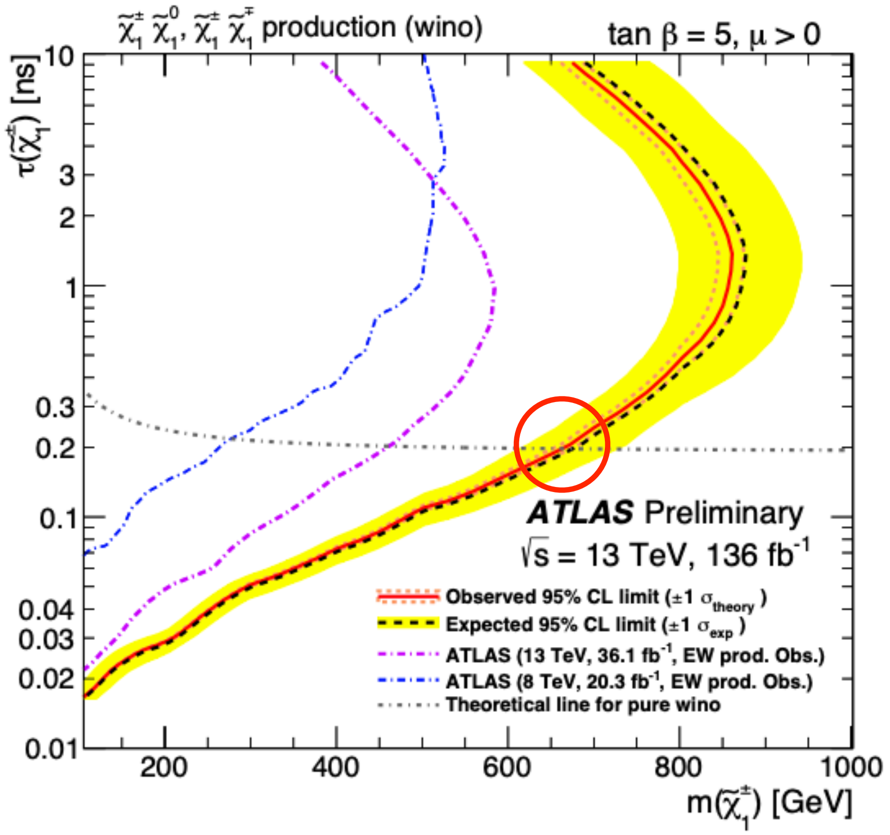
=> long lifetime($\delta m \sim 100\mathrm{MeV}$)

http://www.icepp.s.u-tokyo.ac.jp/~asai/Lecture/Lec3B.pdf

Result

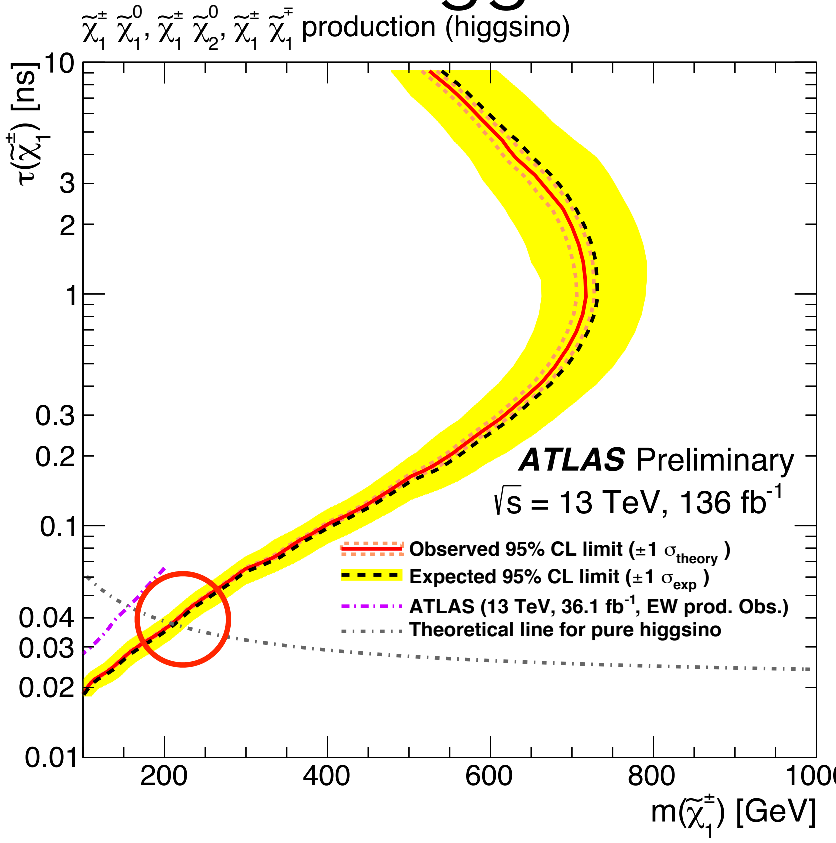
ATLAS-CONF-2021-015

Pure wino



>660GeV

Pure Higgsino



>210GeV

Experimental Search for WIMPs

Generation at accelerators e.g. LHC

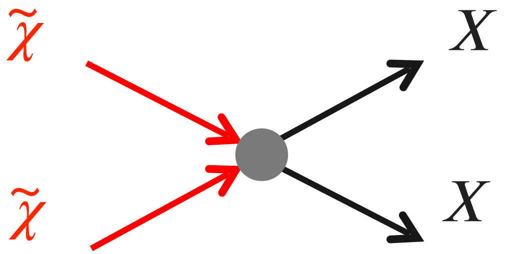
$p + p \rightarrow \ \dots \rightarrow \ \dots + \tilde{a} + \tilde{\chi}$

- indirect detection by missing mass + momentum
- a signal would not yet be a direct proof for the missing Dark Matter of the universe

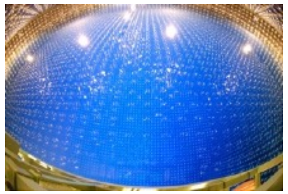
WIMP annihilation in the universe

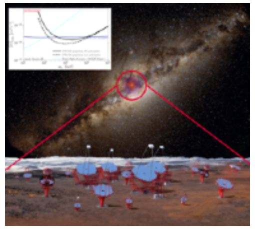
$\tilde{\chi} + \tilde{\chi} \rightarrow \ \dots \rightarrow \ \dots + \upsilon + \tilde{\upsilon} \ , \ \dots \gamma + \gamma$

$\dots \rightarrow \ \dots + e^{+}, \ \dots + \bar{p}$



- search for neutrinos or gammas from large mass accumulations (center of galaxy, sun,…)



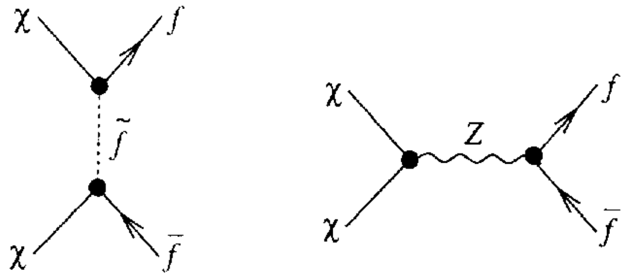


Direct WIMP nucleus scattering

$\tilde{\chi} + N \ \rightarrow \ \tilde{\chi} + N$

- direct proof for WIMPs in halo of our galaxy
- ultra low momentum transfer and rate

Indirect Searches



In regions such as the Galactic Center, dwarf galaxies, the Sun, and the Earth, WIMPs can be trapped by gravity and annihilate into Standard Model particles.

$$\chi\chi \rightarrow b\bar{b},\ W^{+}W^{-} \rightarrow \pi^{0},\ \pi^{\pm} \rightarrow \gamma,\ e^{\pm},\ \nu$$

・**neutrino**:　Super-K, ICECUBE… Big neutrino detectors

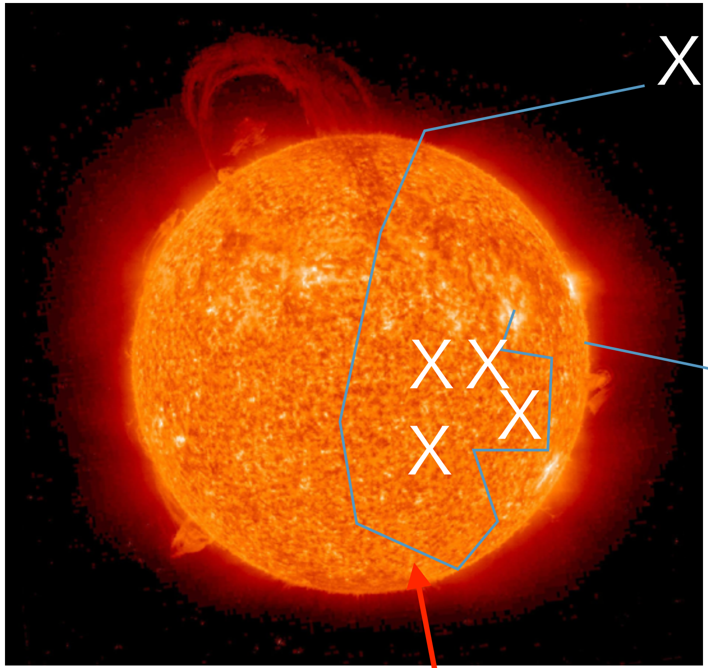
・**positron**: PAMELA, AMS-02…　Satelite

・**gamma-rays**:　Fermi, CTA, HESS…　Telescope

・**unti-proton:** GAPS, BESS　… Balloon

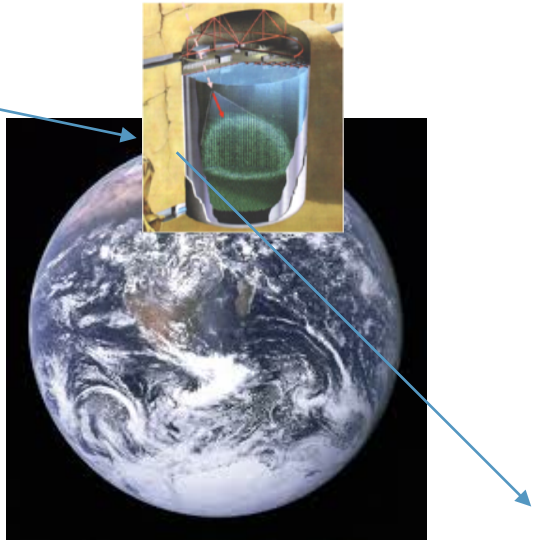
Indirect (Neutrino)

Super-K PRD 102 072002 (2020), PRL 114, 141301 (2015)



Super-K
ICEcube ⋯

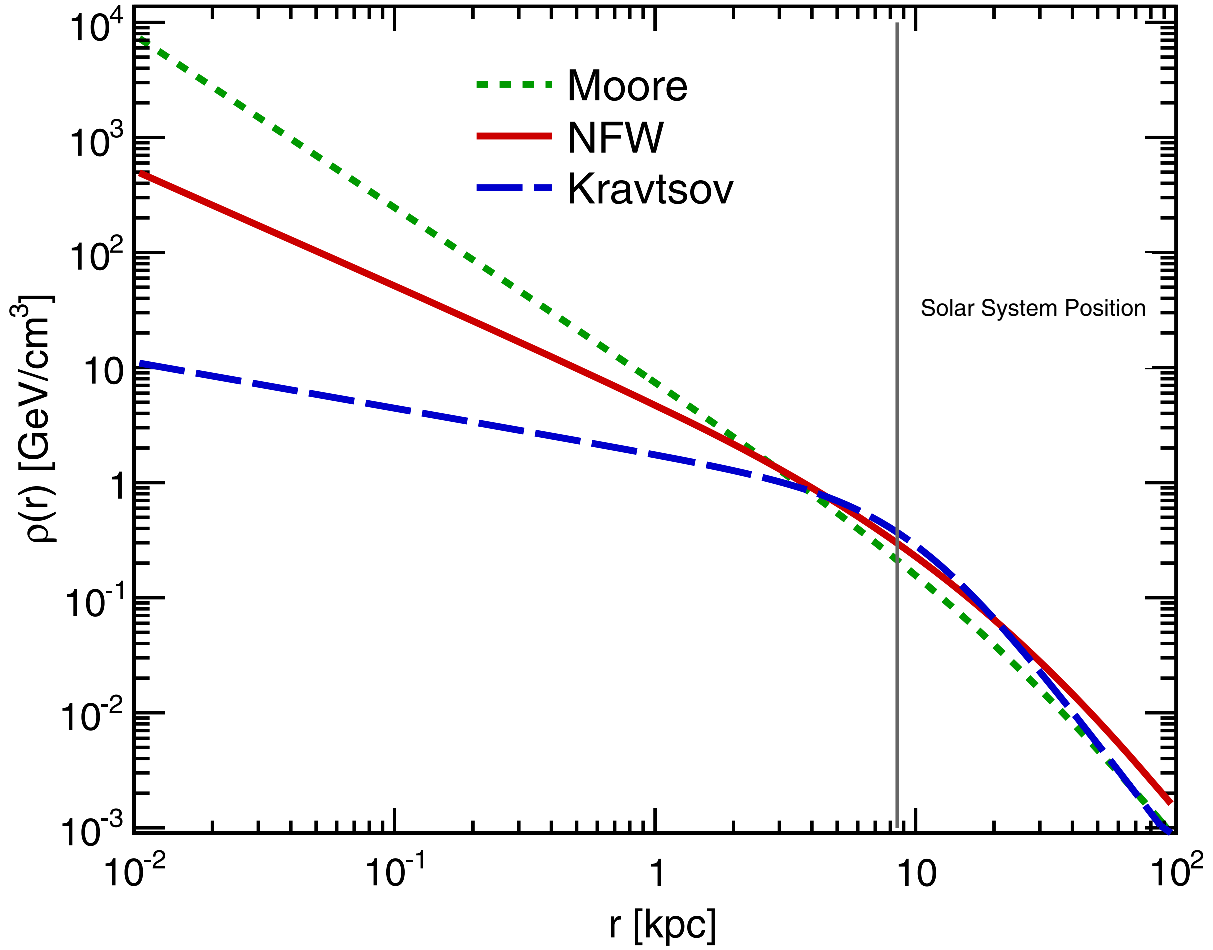
ν



X: dark matter
ν: neutrino

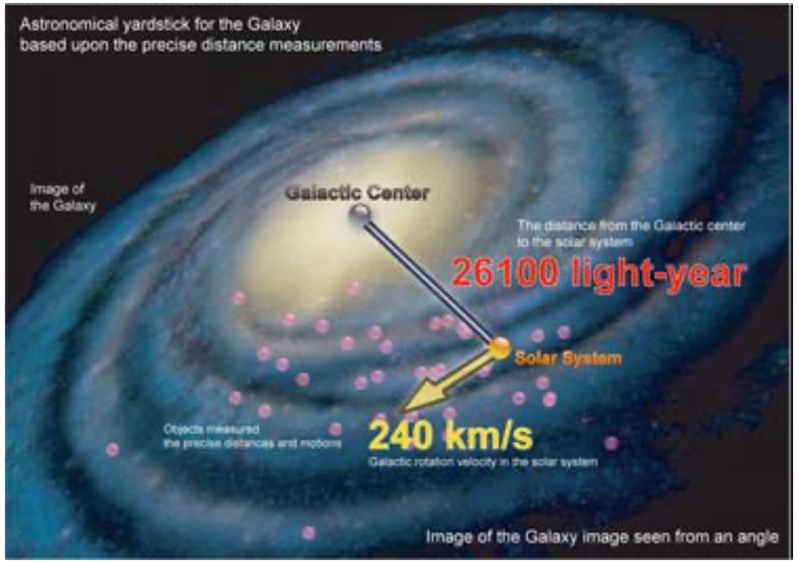
- WIMPs can be trapped by gravity
- scattered with Hydrogen and slow down
- annihilate into neutrinos.

DM density profile



N body simulation

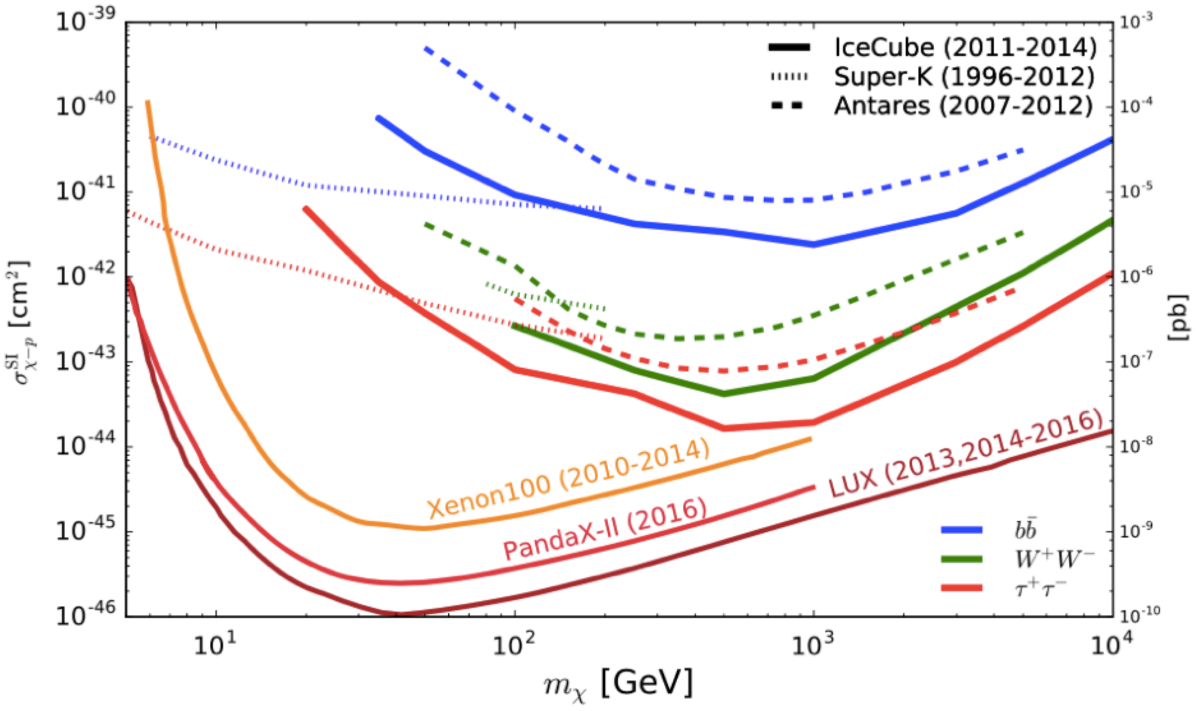
$$\rho(r) = \frac{\rho_0}{(r/r_s)[1+(r/r_s)]^2},$$



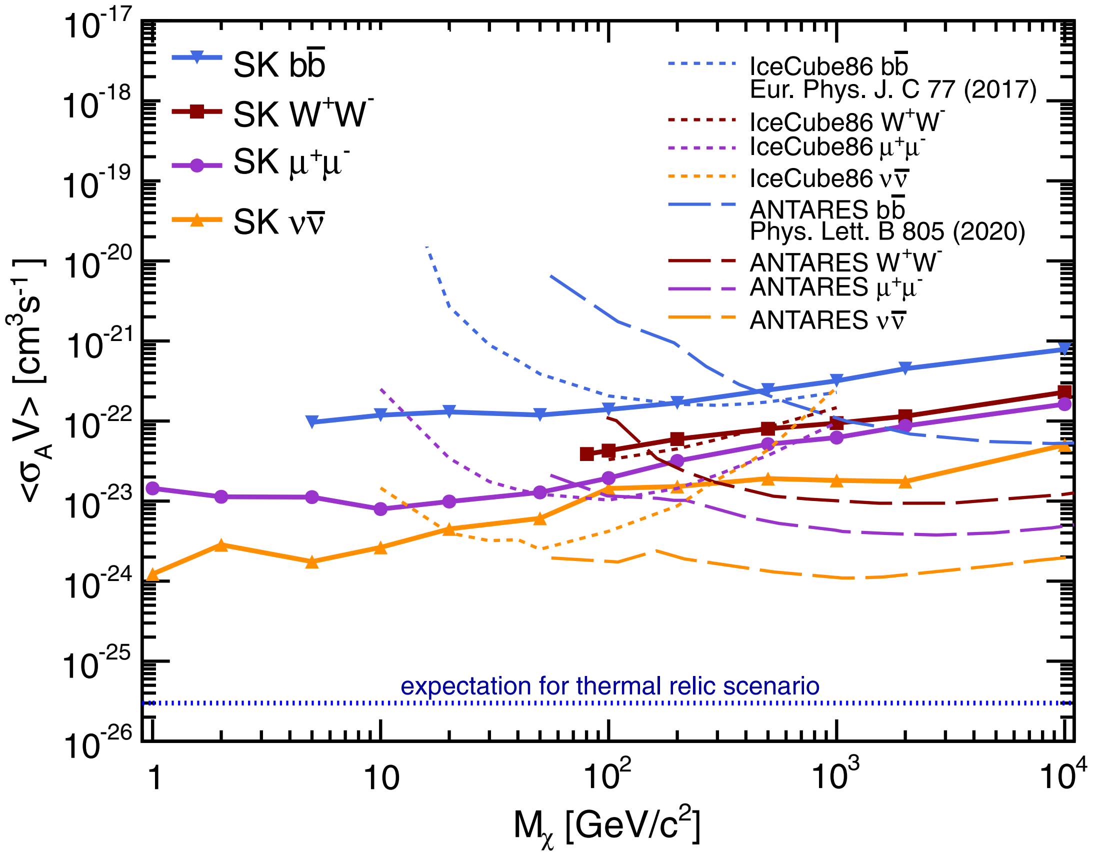
Indirect (neutrino)

Super-K PRD 102 072002 (2020), PRL 114, 141301 (2015)

Sun

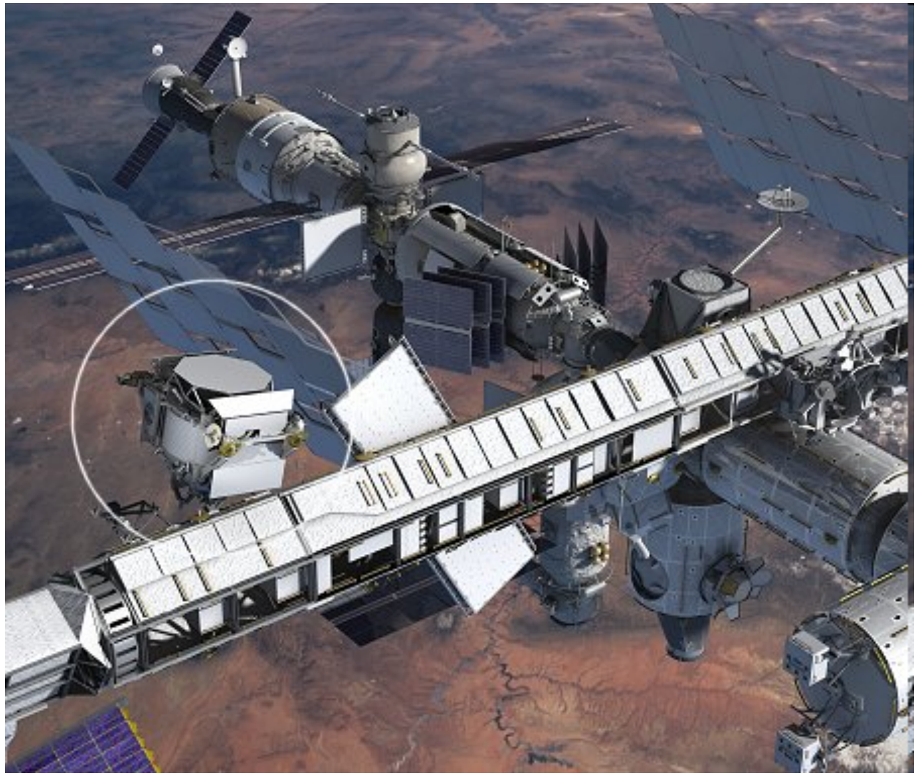


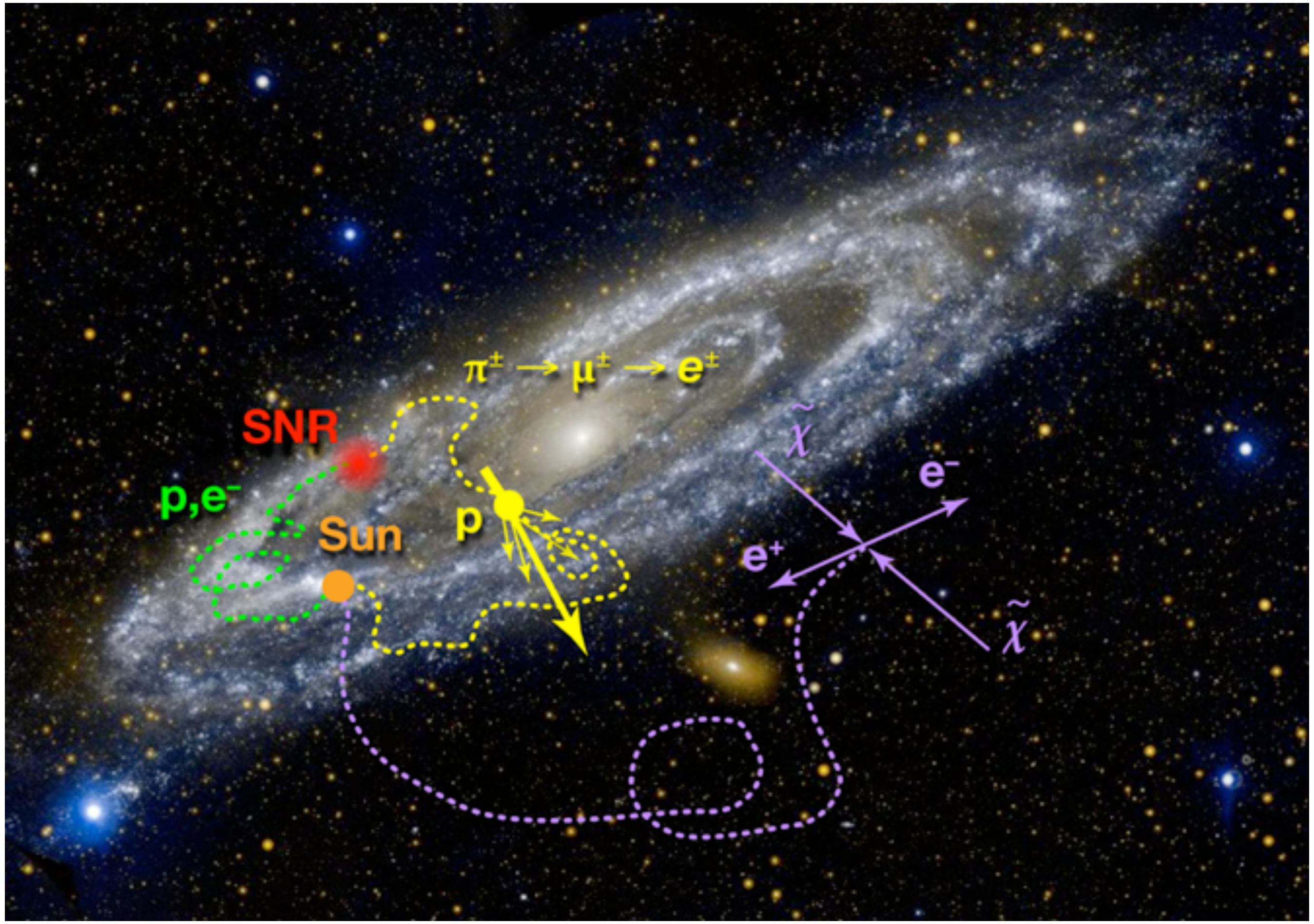
Galactic Center



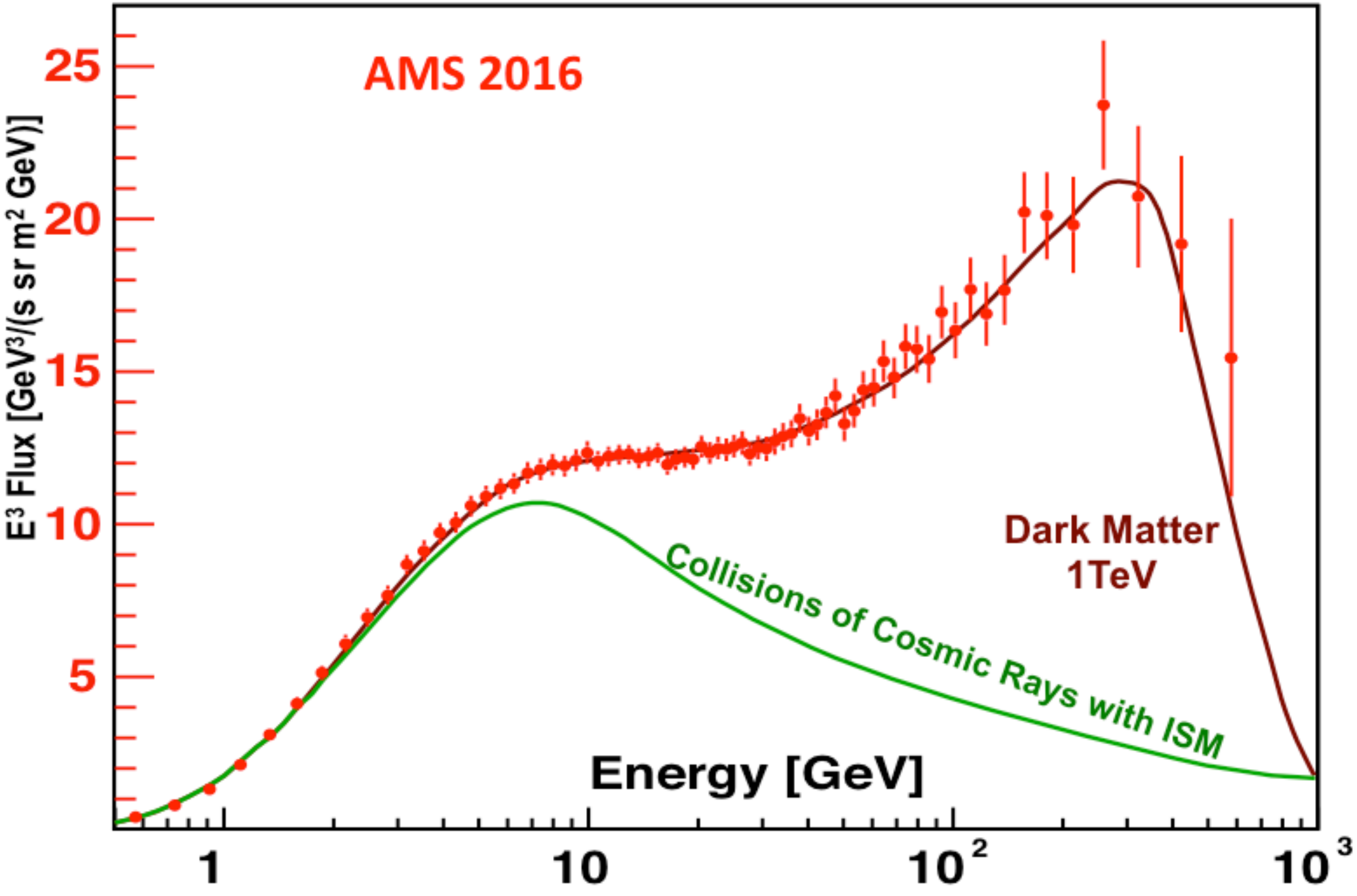
Indirect (positron)

International Space Station}





AMS-02

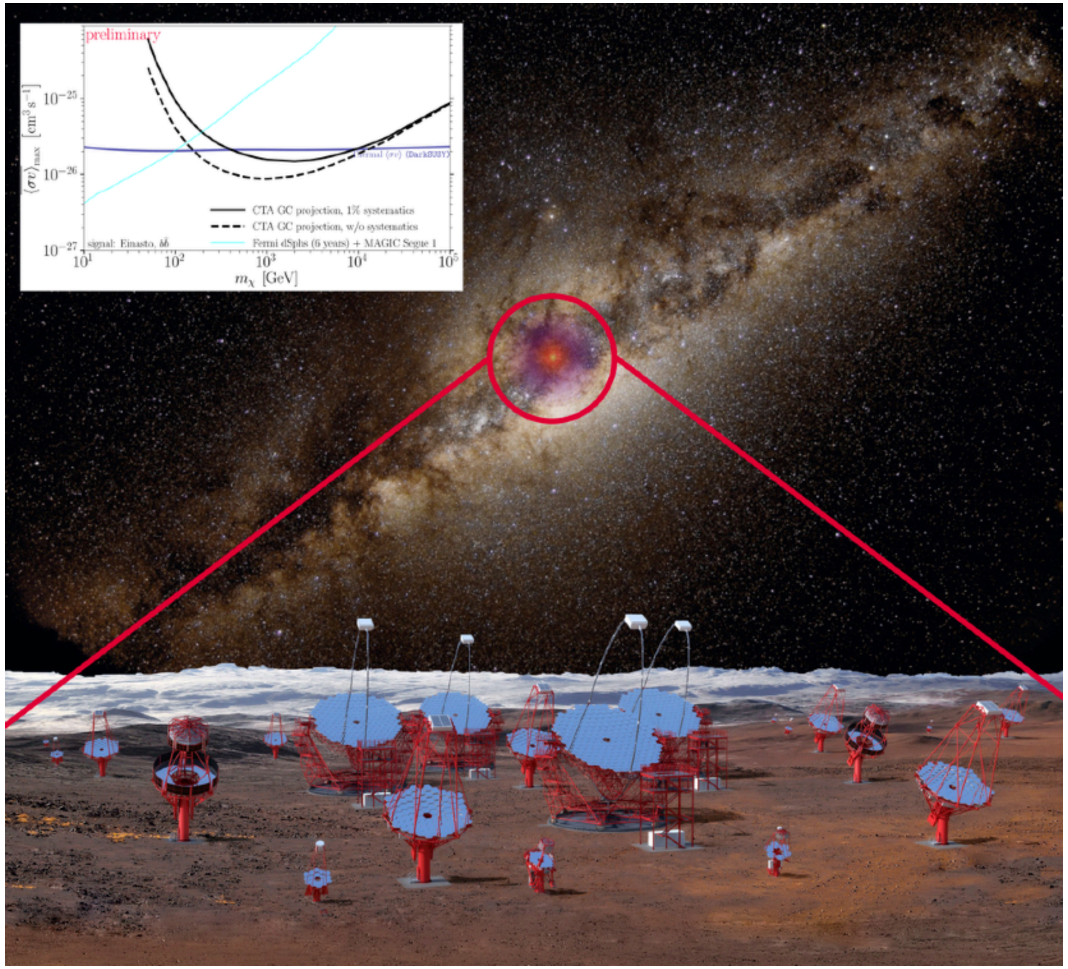


If this excess were due to WIMPs, one would expect signals in other channels, such as antiprotons or gamma rays, which are not observed. Therefore, a pulsar interpretation cannot be excluded.

Indirect (gamma rays)

- Targets are chosen to optimize the signal-to-noise ratio.
- Nearby dwarf galaxies are nearly gas-free and exhibit low gamma-ray and X-ray backgrounds, making them excellent targets.
- The Galactic Center is considered as a subsequent target; however, its strong emission complicates the extraction of a dark-matter signal.

CTA



Relic Density and Sensitivity

$$\Gamma_f^A = c\frac{\rho_{\rm DM}^2}{m_{\rm DM}^2}\langle\sigma v\rangle N_f^A,$$

- flux from object

$$\phi_f = \int_{\Delta\Omega} d\Omega \int_{\rm l.o.s.} dl \frac{\Gamma_f}{4\pi}.$$

production

solid angle

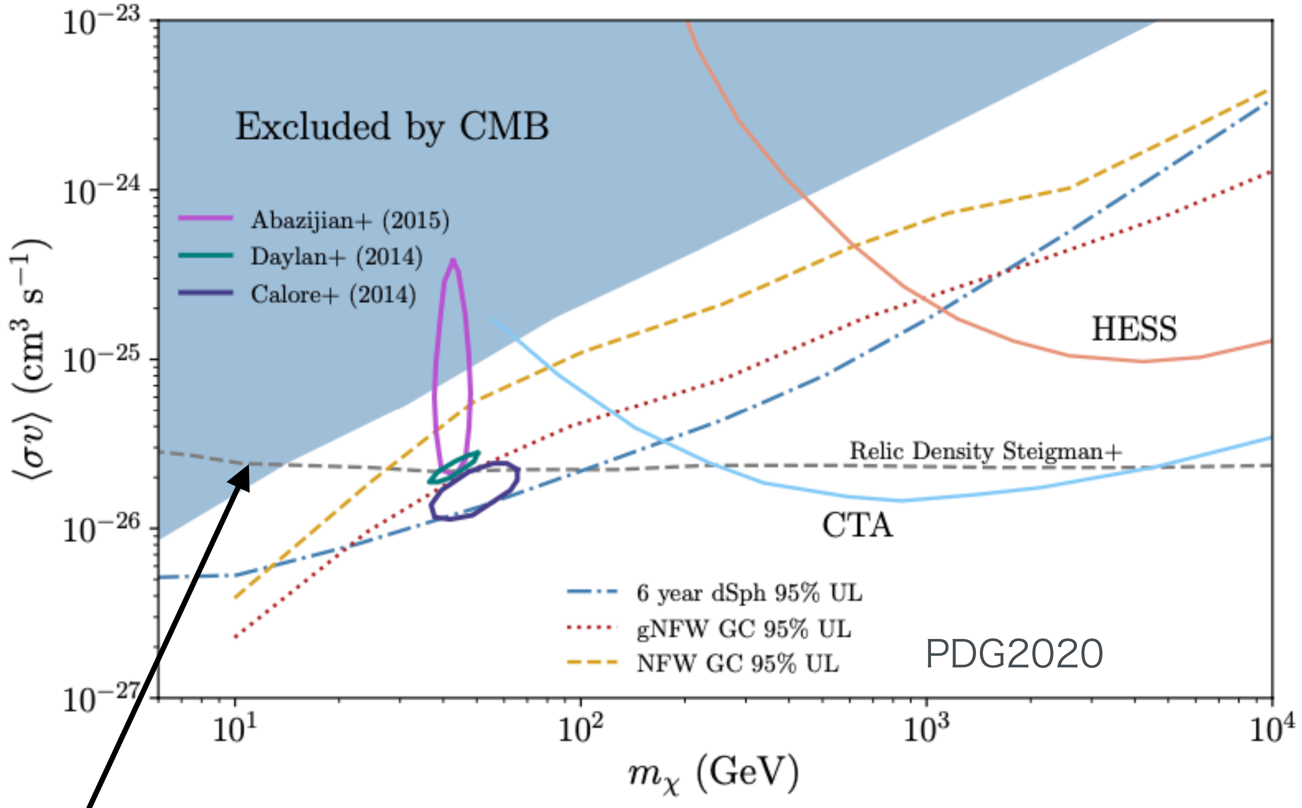
- Particle-physics term × astrophysical factor (J-factor)

$$J_{\Delta\Omega}(\psi) = \int_{\Delta\Omega}\int_{\rm l.o.s.(\psi)} \rho_{\rm DM}^2(l,\Omega)\, dl d\Omega.$$

- Assuming a uniform density ρ, a source with radius r, and distance d, in the limit where d >> r.

$$J \simeq \frac{4\pi r^3 \bar{\rho}_{\rm DM}^2}{3d^2}.$$

- <σv> -> Measurement



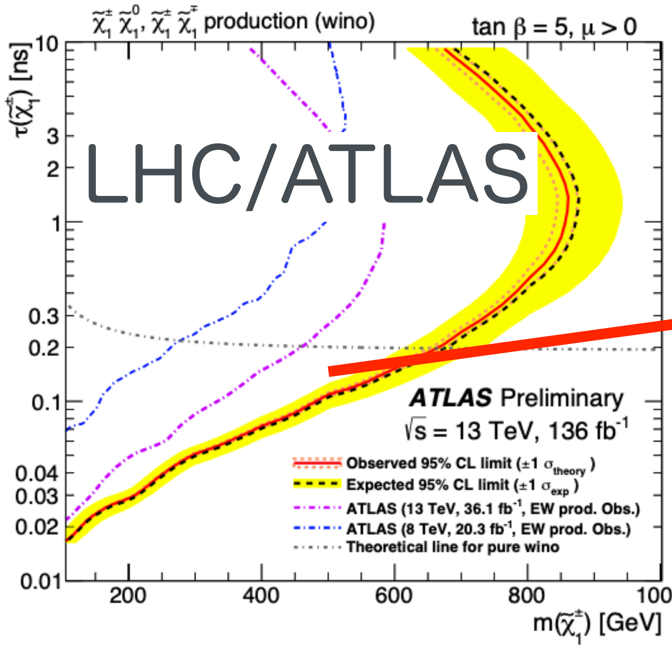
freeze out: 3×10^{-26}

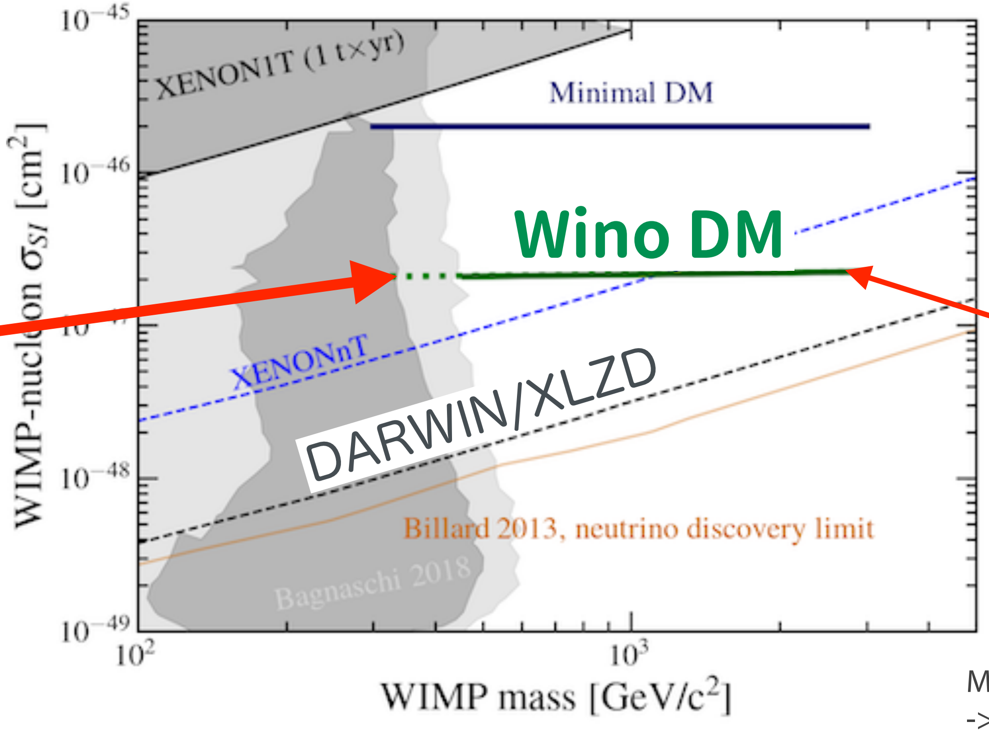
WIMP DM Search in 2030'

'minimal dark matter' scenario

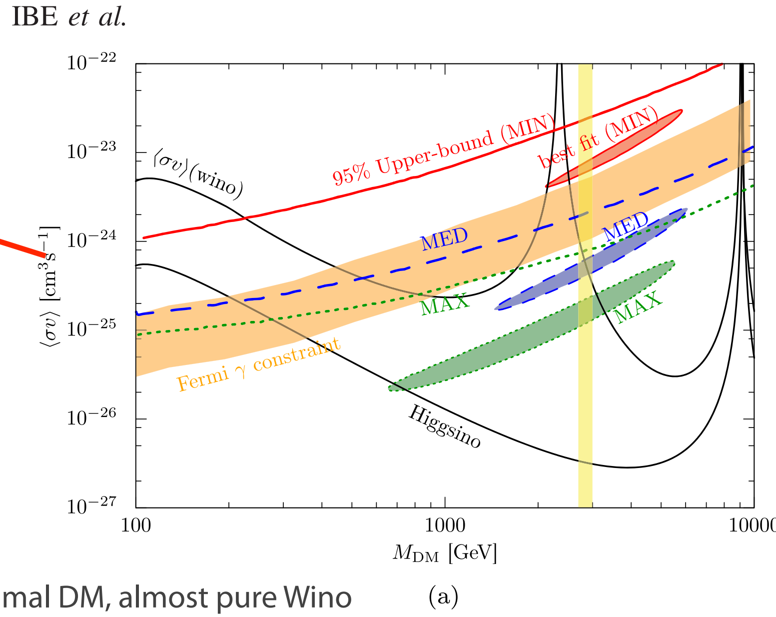
(almost) Wino DM

- WIMP interacting with the SM particles via the SM weak interaction.
- a very predictive and simple model (2×10^{-47} cm^2)





CTA(Indirect)



Minimal DM, almost pure Wino
-> Hisano, Ishiwata, Nagata JHEP06(2015)097

Collider, Indirect, Direct Search Complementarity

Experimental Search for WIMPs

Generation at accelerators e.g. LHC

$p + p \rightarrow \; \ldots \rightarrow \; \ldots + \tilde{a} + \tilde{\chi}$

- ➢ indirect detection by missing mass + momentum
- ➢ a signal would not yet be a direct proof for the missing Dark Matter of the universe

WIMP annihilation in the universe

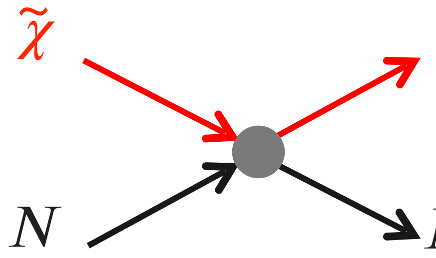
$\tilde{\chi} + \tilde{\chi} \rightarrow \; \ldots \rightarrow \; \ldots + \upsilon + \tilde{\upsilon} \;, \; \ldots \gamma + \gamma$

$\ldots \rightarrow \; \ldots + e^{+}, \; \ldots + \bar{p}$

- ➢ search for neutrinos or gammas from large mass accumulations (center of galaxy, sun,…)

Direct WIMP nucleus scattering

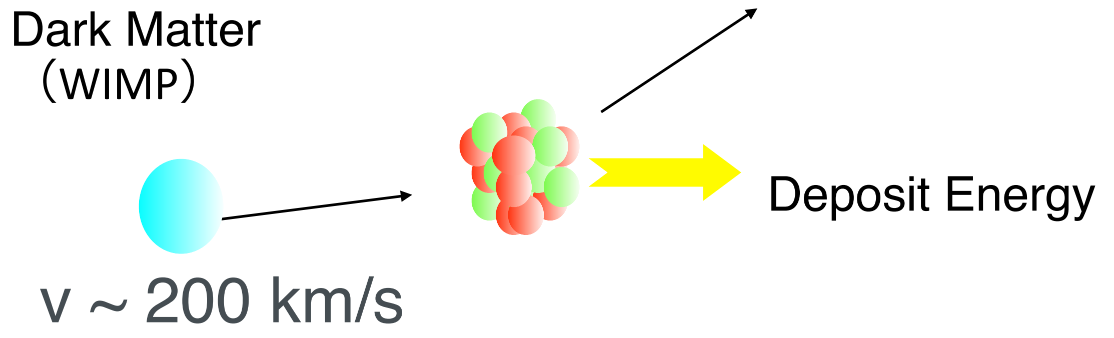
$\tilde{\chi} + N \; \rightarrow \; \tilde{\chi} + N$



- ➢ direct proof for WIMPs in halo of our galaxy
- ➢ ultra low momentum transfer and rate

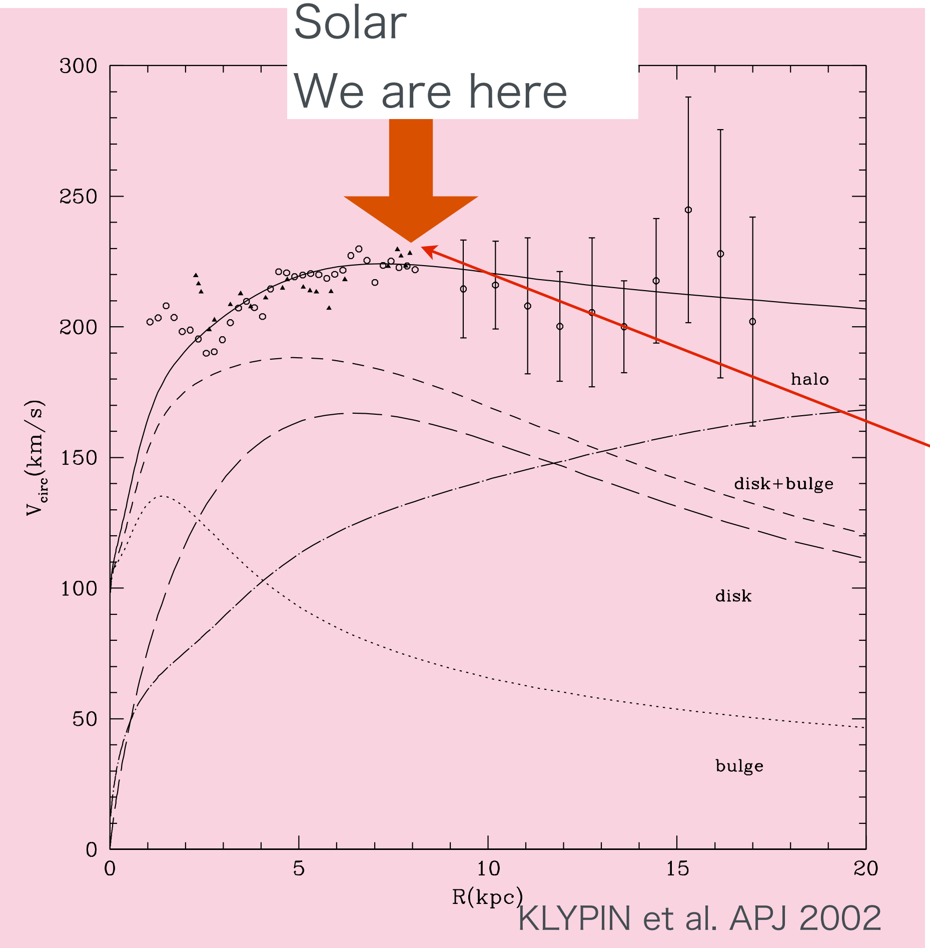
WIMP Direct Searches

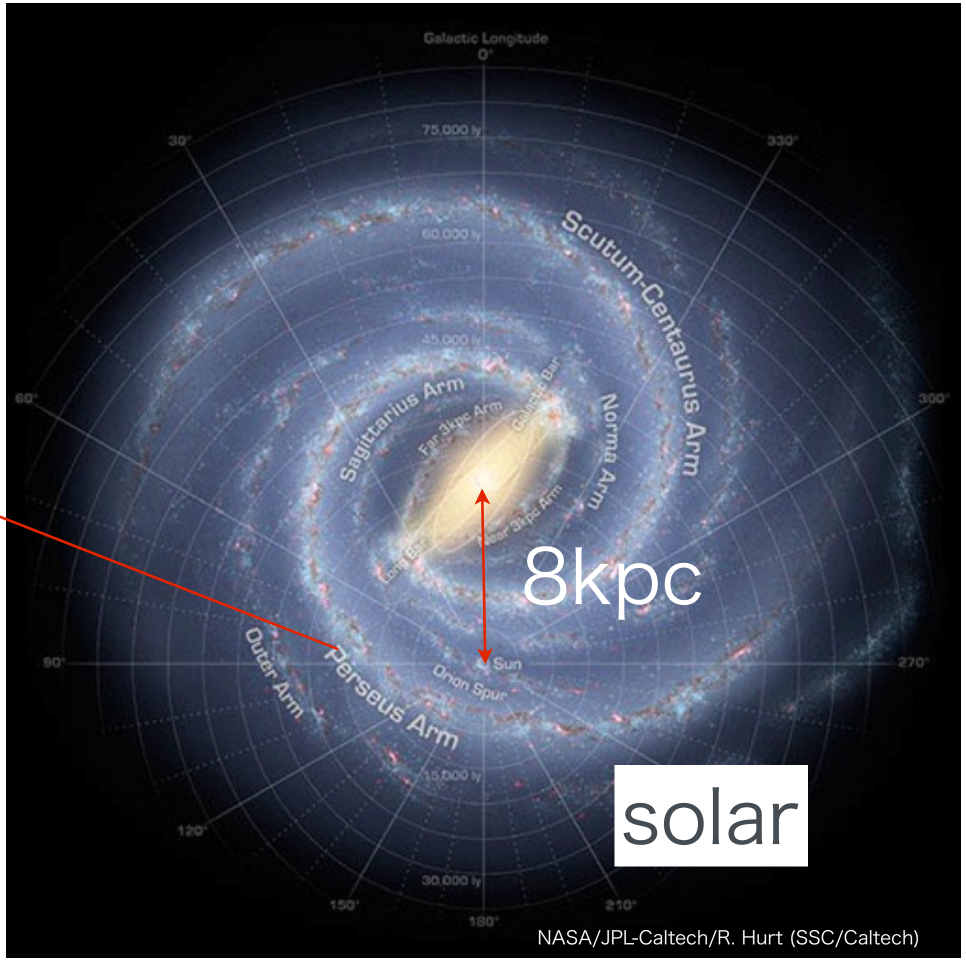
Direct Search



- WIMP mean velocity is about 230 km/s at the location of our solar system.
- WIMPs interact with ordinary matter through elastic scattering on nuclei.
- Typical nuclear recoil energies are of order of 1 to 100 keV.

Dark matter in our Galaxy





~0.3GeV/cm3 @ Solar system

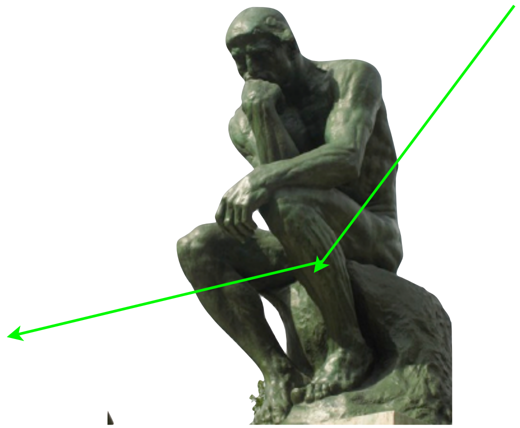
Masaki Yamashita, ISEE NagoyaU

DM arounds us

$\rho_{dm} = 0.3\ \mathrm{GeV/cm^3}$

a few WIMPs/Liter

(~ 100GeV WIMP mass case)



10^9 WIMPS/sec go through our body

How can we detect dark matter that interacts only very rarely with ordinary matter?

Practice : Dark Matter Passing Through Your Body

Constants and useful relations

Use the following values when needed:

$$\rho_{\rm DM} \approx 0.3\,{\rm GeV/cm^3},$$
$$v_0 \approx 220\,{\rm km/s},$$
$$N_A = 6.0 \times 10^{23}\,{\rm mol^{-1}},$$

Human body surface ~ 1 m^2

Problem 1: Dark Matter Number Density

The local dark matter density is approximately

$$\rho_{\rm DM} \approx 0.3\,{\rm GeV/cm^3}.$$

(a) Assume the dark matter particle mass is

$$m_\chi = 100\,{\rm GeV}.$$

Compute the number density n_χ.

(b) Assuming the typical dark matter velocity is

$$v = 220\,{\rm km/s},$$

calculate the dark matter flux

$$\Phi = n_\chi v.$$

(c) Express the result in units of

$${\rm cm^{-2}s^{-1}}.$$

Solution

(a) The number density is

$$n_\chi = \frac{\rho_{\mathrm{DM}}}{m_\chi} = \frac{0.3\,\mathrm{GeV/cm^3}}{100\,\mathrm{GeV}} = 3.0 \times 10^{-3}\,\mathrm{cm^{-3}}.$$

(b) Using $v = 2.2 \times 10^7\,\mathrm{cm/s}$,

$$\Phi = n_\chi v = (3.0 \times 10^{-3})(2.2 \times 10^7) = 6.6 \times 10^4\,\mathrm{cm^{-2}s^{-1}}.$$

(c) Therefore,

$$\boxed{\Phi \approx 6.6 \times 10^4\,\mathrm{cm^{-2}s^{-1}}.}$$

(a) Assume the cross-sectional area of a human body is approximately

$$A \approx 1\,\mathrm{m^2}.$$

Estimate how many dark matter particles pass through your body per second.

Solution

Using

$$\Phi \approx 6.6 \times 10^4\,\mathrm{cm^{-2}s^{-1}},$$

the number passing through per second is

$$N = \Phi A = (6.6 \times 10^4)(10^4) = 6.6 \times 10^8\,\mathrm{s^{-1}}.$$

Therefore,

$$\boxed{N \approx 7 \times 10^8\,\mathrm{s^{-1}} \sim 10^9\,\mathrm{s^{-1}}.}$$

Using

$$\Phi \approx 6.6 \times 10^4\,\mathrm{cm^{-2}s^{-1}},$$

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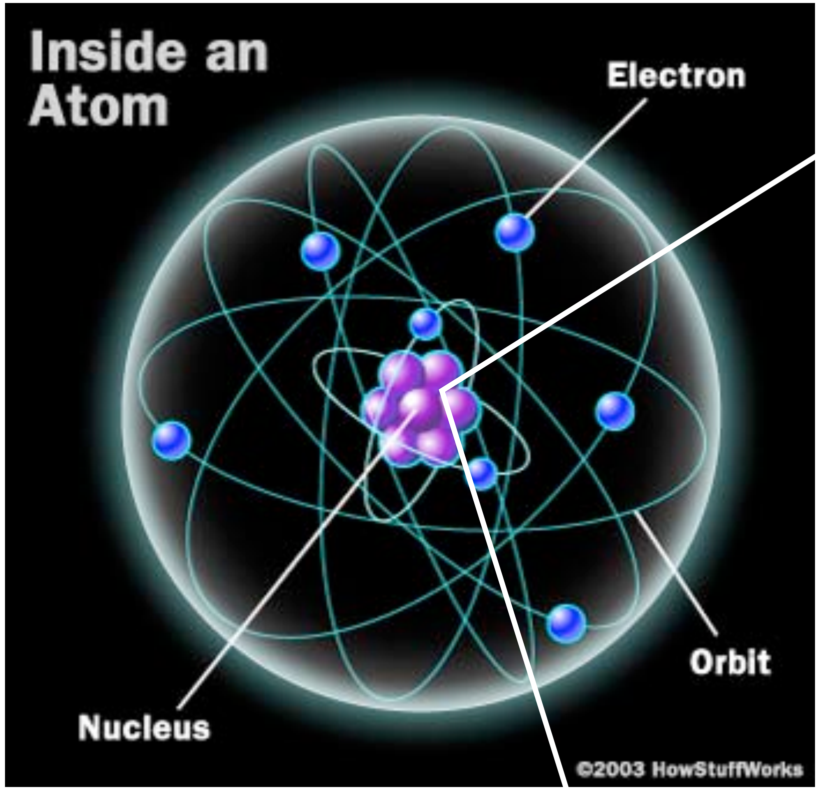
Interaction with dark matter

Goodman and Witten PRD(1985)

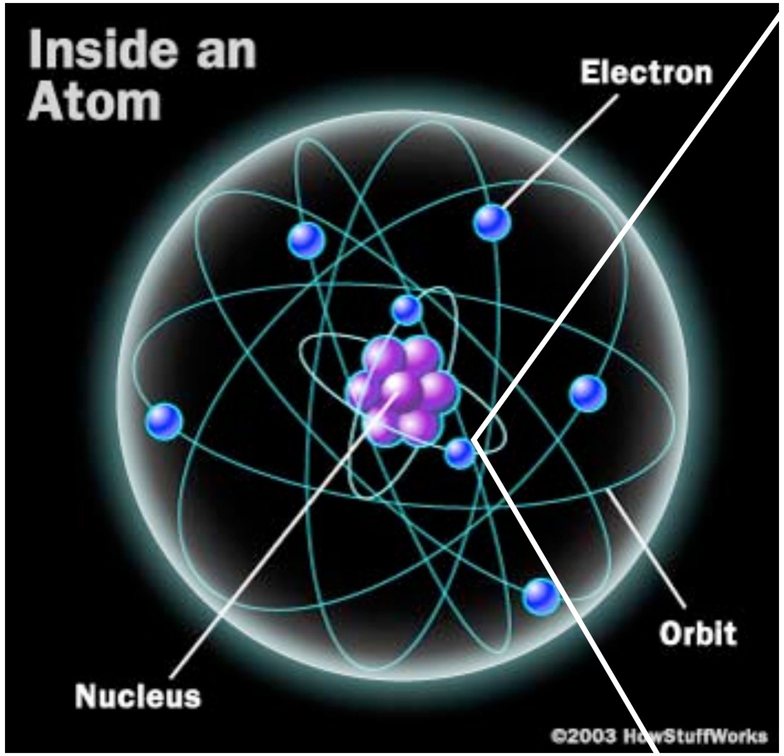
nuclear recoil



fast neutron, neutrino

WIMP

electronic recoil



-U/Th/^{40}K etc background

How to detect? Radiation detector

- incoming particle interacts with atom in your detector.
- ionize or excite atom
- produce scintillation light, charge, phonon …
  - light ->detected by photo sensors (PMT, SiPM)
  - charge-> collect charges by applying an electric field. (Ge, Time projection Chamber)
  - phonon-> bolometer (low temperature detector, Si, Ge …)
- measure deposited energy by counting those quanta

Deposit energy in a detector

$$E_R = r\frac{(1-\cos\theta)}{2}E_W$$

$$r = \frac{4M_\chi M_N}{(M_\chi + M_N)^2},$$

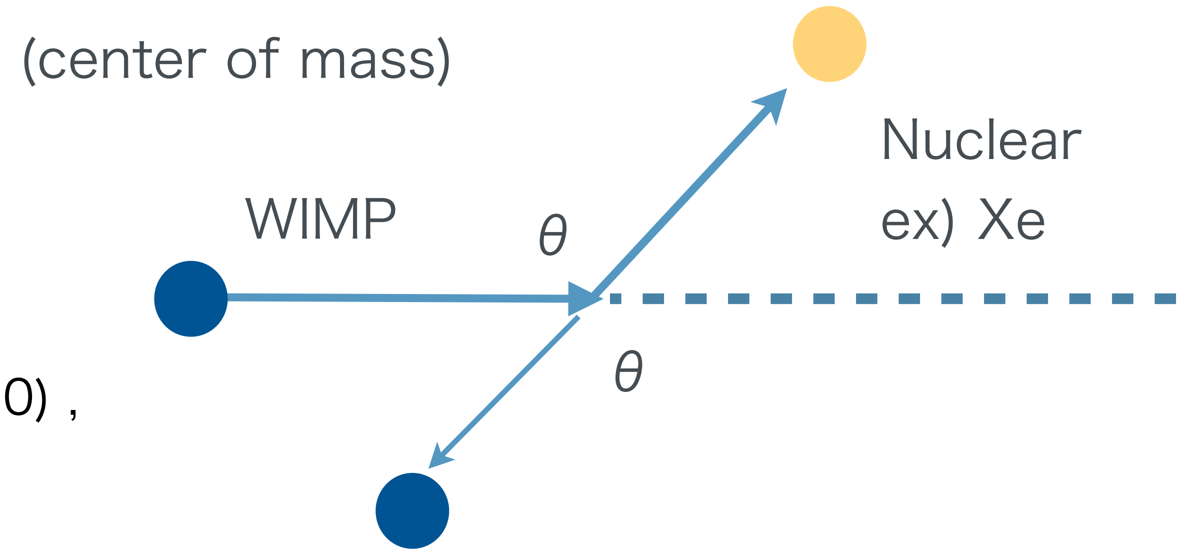
Let's assume:

M_W = 100 GeV/c^2 , MT = 100 GeV/c^2 (Xe :A ~130) ,

r = 1

WIMP velocity: v= 220 km/sec ~ 0.75 X 10^{-3} c

E_R?



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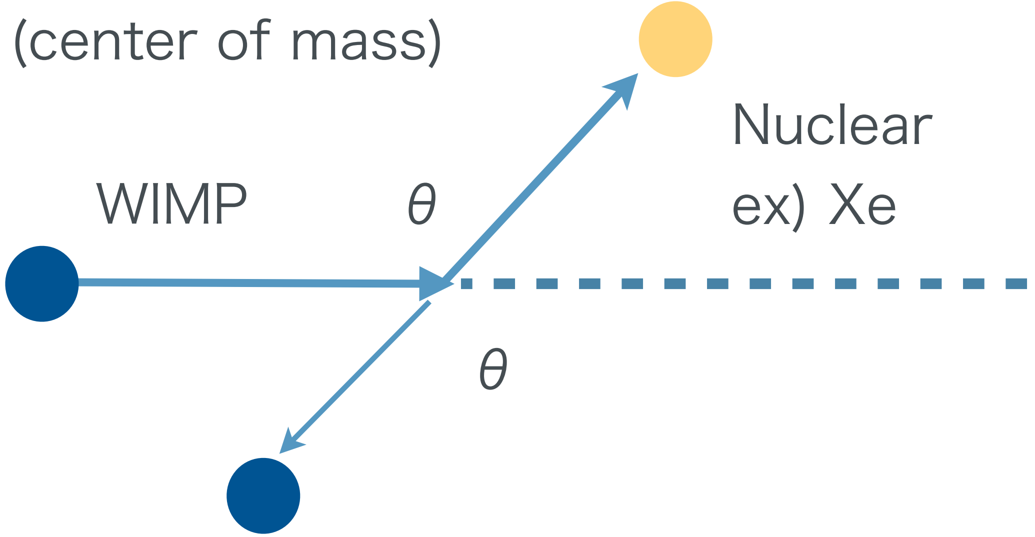

Let's assume:

Mw = 100 GeV/c2 , MT = 100 GeV/c2 (Xe :A ~130)

, r = 1

WIMP velocity: v= 220 km/sec ~ 0.75 X 10^{-3} c

$$E_R = \frac{1}{2}M_w\beta^2c^2$$

$$= 1/2 \times 100\mathrm{GeV/c^2} \times (0.75 \times 10^{-3})^2$$

$$\approx 28\mathrm{keV}$$