FY2024 "What is dark matter?
- Comprehensive study of the huge discovery space in dark matter"
2024.4.24

Dark Matter
Halo / Signal / Particle

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recap of our strategy:

as A02, very-heavy dark matter (VHDM) is:

- typically $m_{\mathrm{DM}} \gtrsim \mathcal{O}(1)$ TeV,

  which is beyond the accessibility with current collider experiments.

- searched through observations of high-energy particles from our Universe (γ, ν, cosmic-ray) . **indirect search**

- partially within the range of well-motivated weakly-interacting massive particles (WIMP) category.

- believed to be produced sometimes in a different mechanism from the thermal freeze-out.

dark matter halo

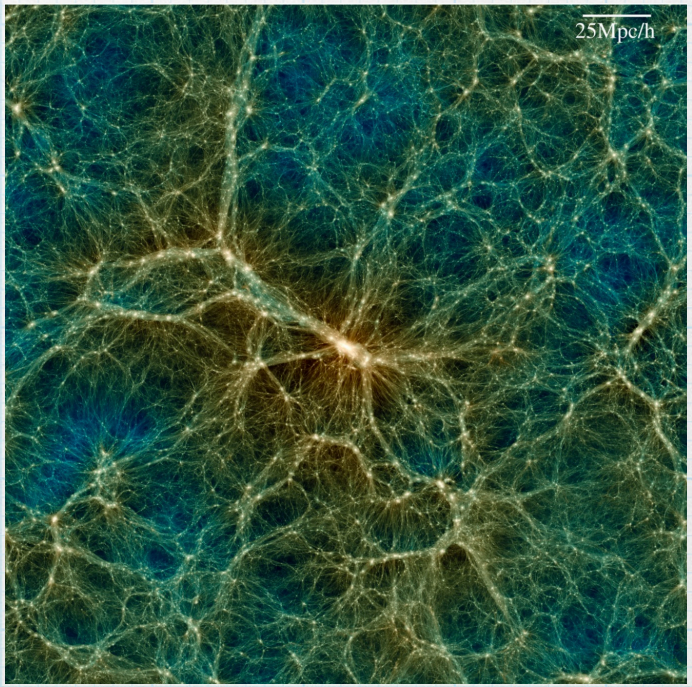
halo: the building block

dark matter = non-baryonic matter-like component

halo formation through gravitational interaction
↔requirement to realize baryonic structures

- naive initial condition:
  CMB power spectrum
- halo mass range:
  $\sim \mathcal{O}(10^{-6}? - 10^{16}) M_\odot$
- characteristics: mass function/
  density profile/ ⋯

Ishiyama et al., 2021



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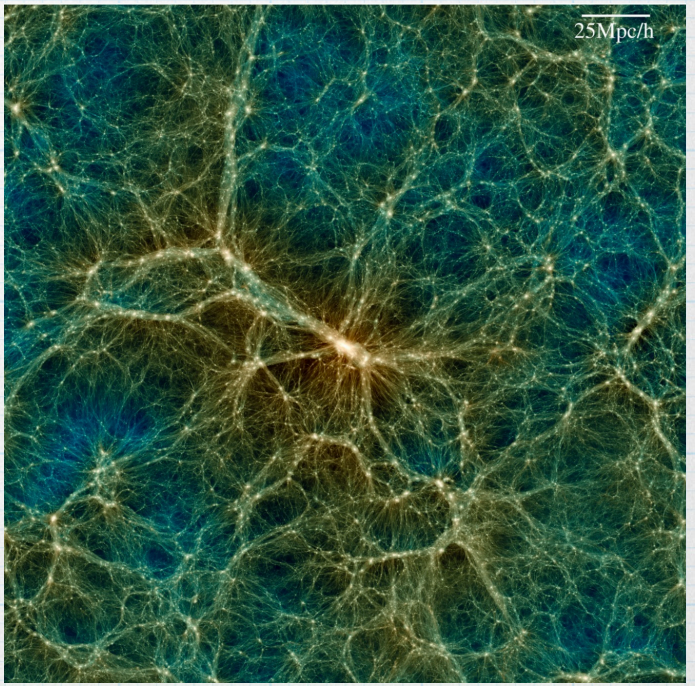


- naive initial condition:
  CMB power spectrum
  indicator in cosmology
- halo mass range:
  $\sim \mathcal{O}(10^{-6}? - 10^{16})M_{\odot}$
  requirement of wide-coverage
- characteristics: mass function/
  density profile/ ⋯
  critical issue in conventional indirect search

tie-up with C02

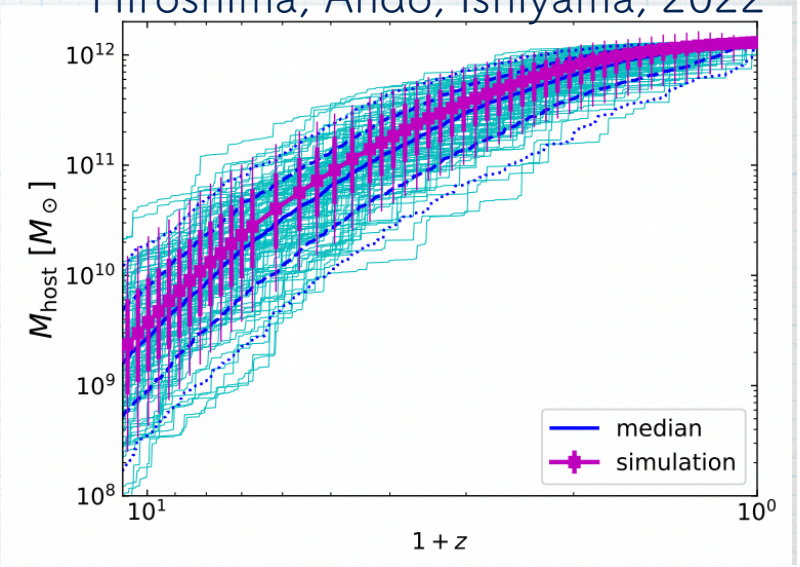
analytic calculation of halo

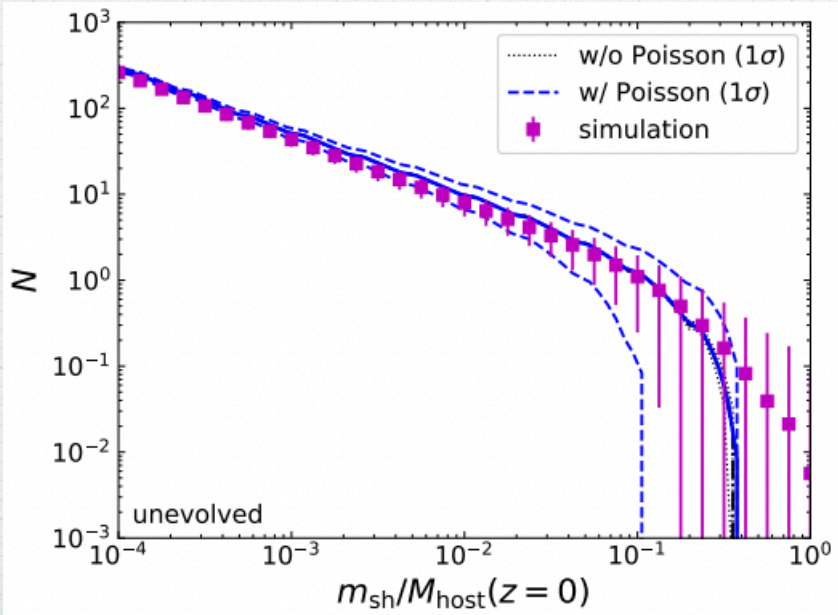
Extended Press-Schechter formalism (EPS)

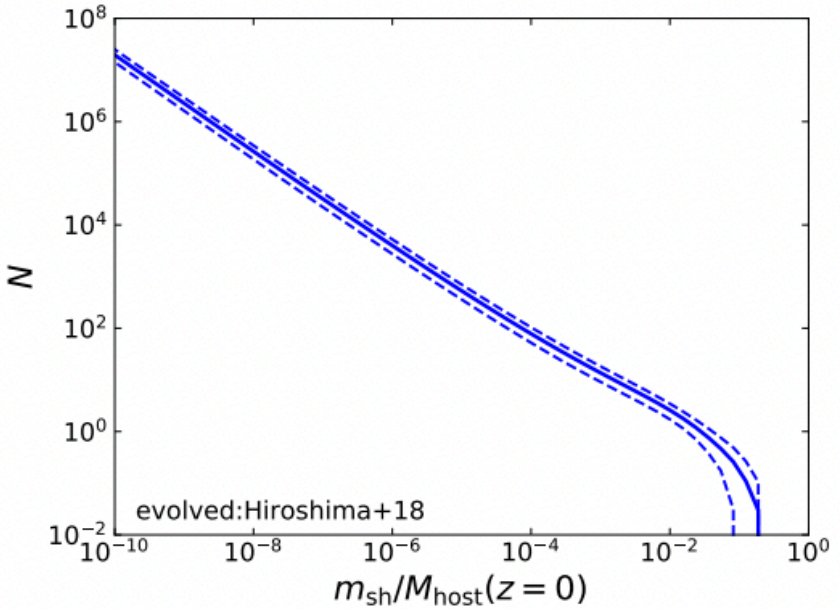
- 2 parameters: collapse redshift & mass scale $(\delta(z), \sigma(m))$
- distribution function:

$$f = \frac{1}{\sqrt{2\pi}} \frac{\delta(z+\Delta z) - \delta(z)}{[\sigma^2(m) - \sigma^2(M)]^{3/2}} \exp\left[-\frac{(\delta(z+\Delta z) - \delta(z))^2}{2(\sigma^2(m) - \sigma^2(M))} \right]$$

Hiroshima, Ando, Ishiyama, 2022



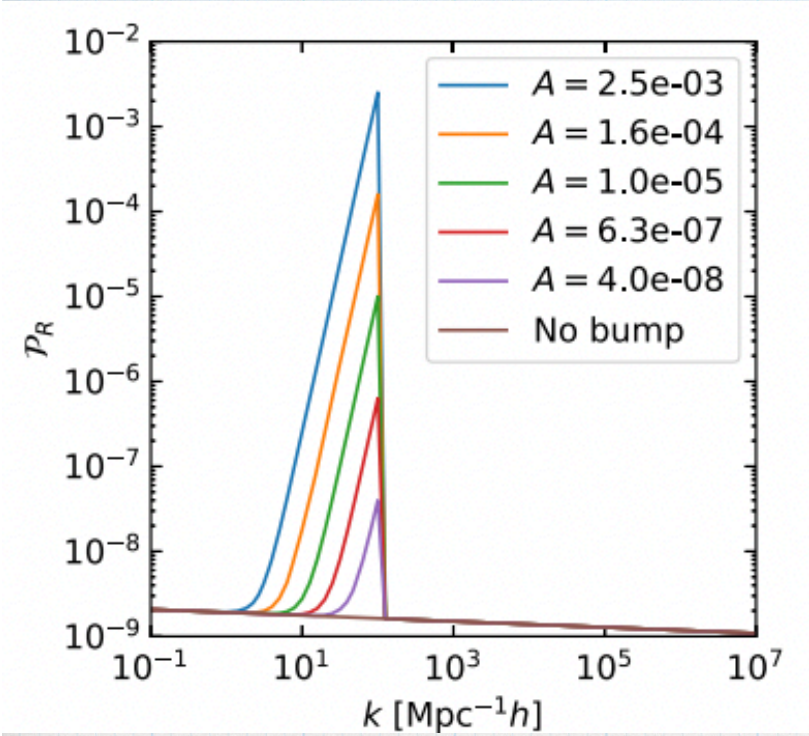




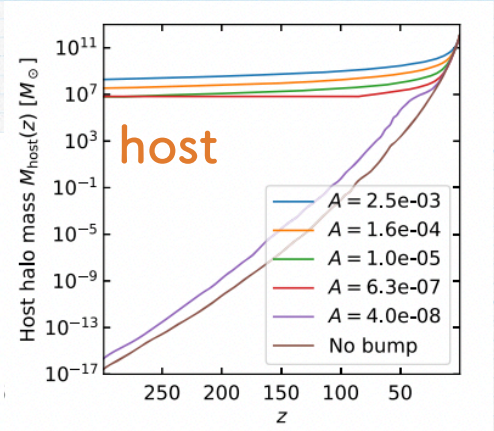
tie-up with C02

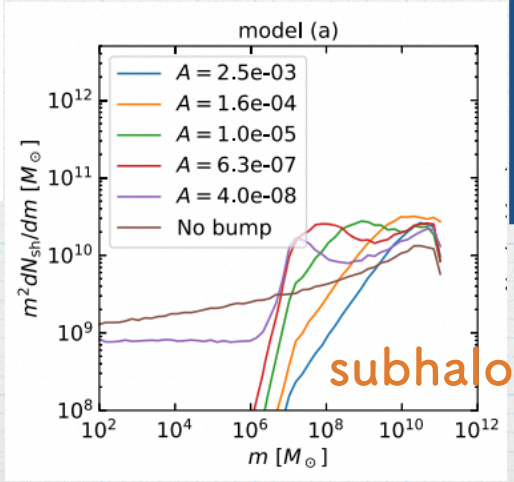
halo as a cosmology probe

halo mass function with initial condition beyond CMB

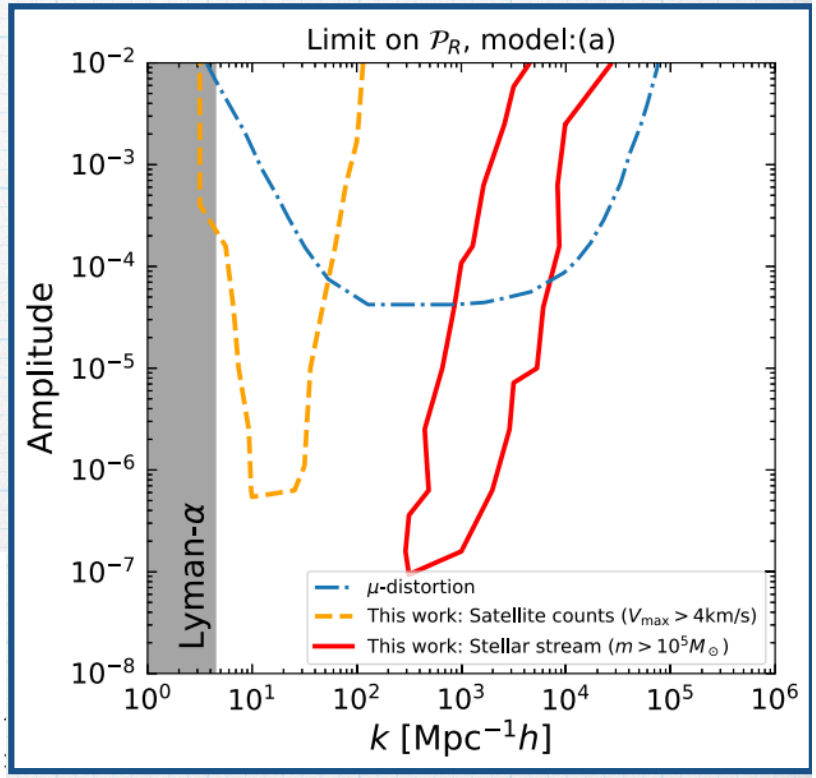


$$\mathscr{P}(k) \rightarrow \sigma(M)$$



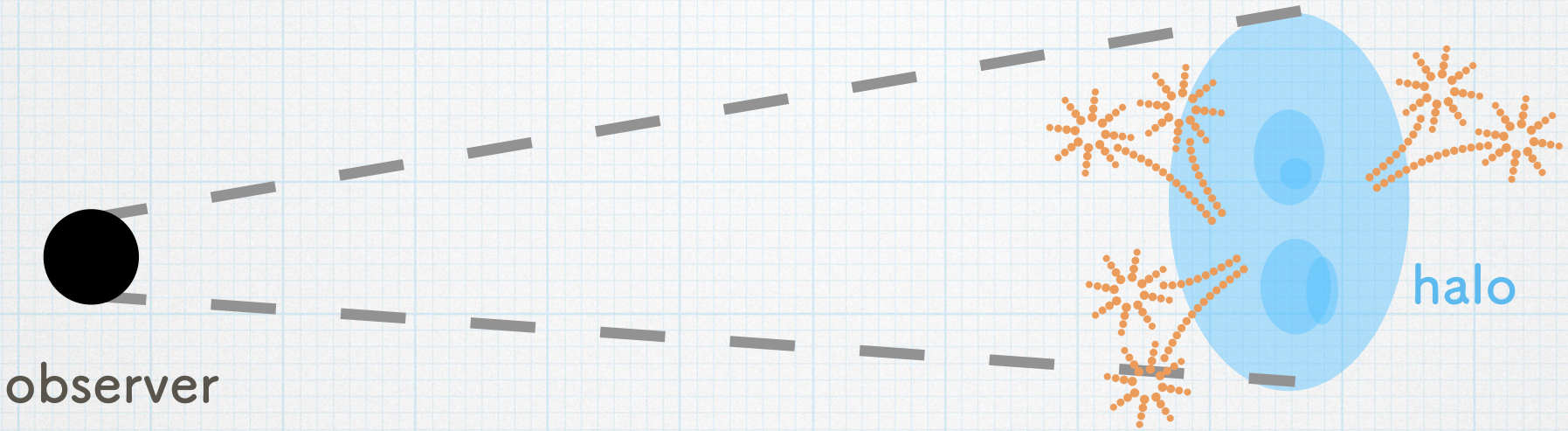


Ando, Hiroshima, Ishiwata, 2022



dark matter signal

conventional indirect search:



annihilation $$\phi = \frac{1}{8\pi}\frac{\langle\sigma v\rangle}{m_{\rm DM}^2}\int_{E_{\rm th}}^{m_{\rm DM}}\frac{dN}{dE}dE \cdot \boxed{\int_{\Delta\Omega} d\Omega \int_{l.o.s} ds \rho_{\rm DM}^2}$$

J -factor

decay $$\phi = \frac{1}{4\pi}\frac{\Gamma}{m_{\rm DM}}\int_{E_{\rm th}}^{m_{\rm DM}}\frac{dN}{dE}dE \cdot \boxed{\int_{\Delta\Omega} d\Omega \int_{l.o.s} ds \rho_{\rm DM}}$$

D-factor

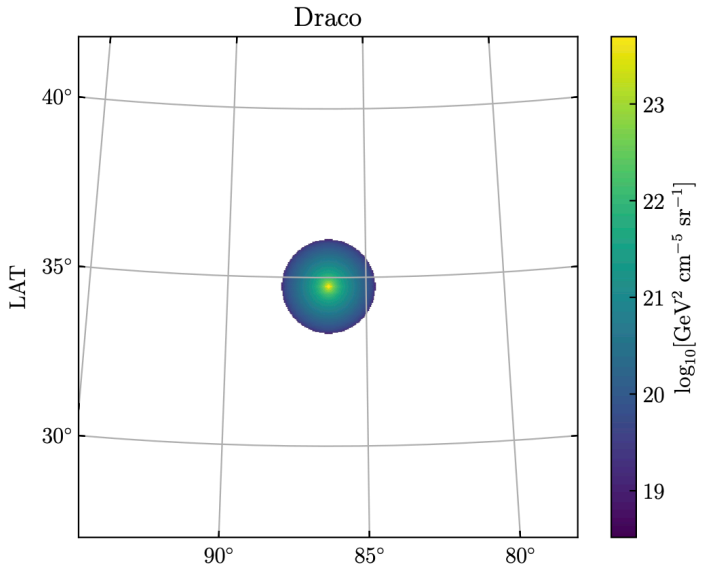
understanding of halo is necessary

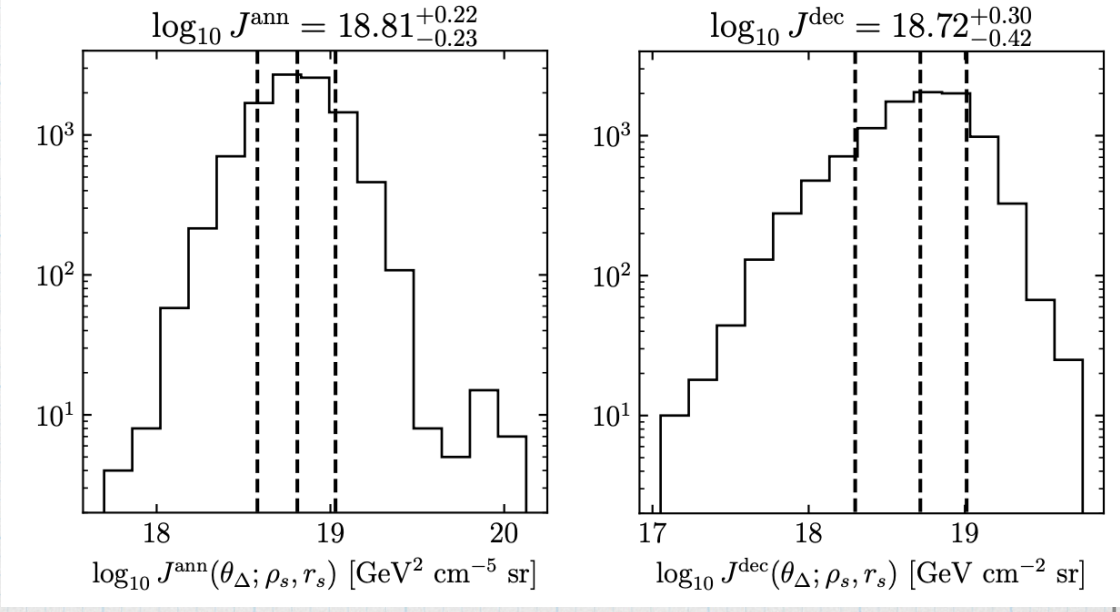
VHDM in satellite galaxies

- satellite of the Milky Way
- clean environments (inactive star formation)
- high J-factor objects
- J-factor uncertainty needs to be addressed

(J/D-factor with EPS subhalo prior) × (cascade model) × (Fermi-LAT data)

Song, Hiroshima, Murase, 2024



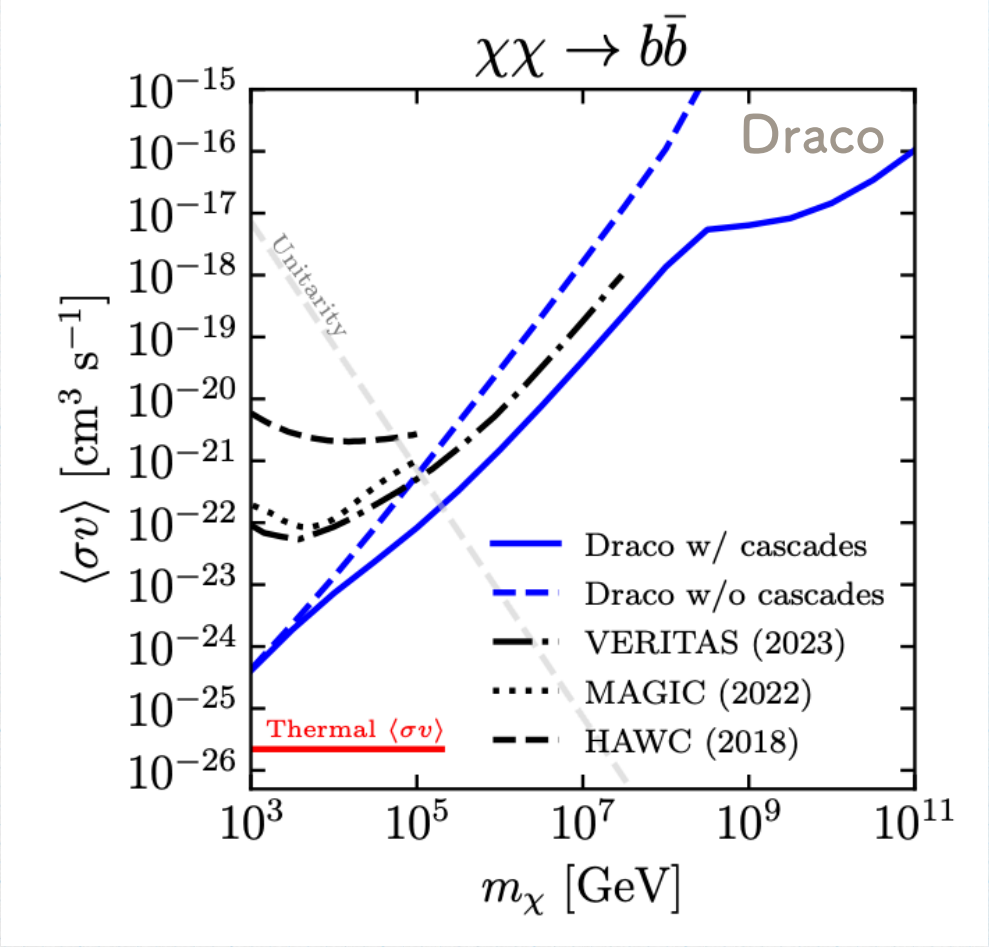


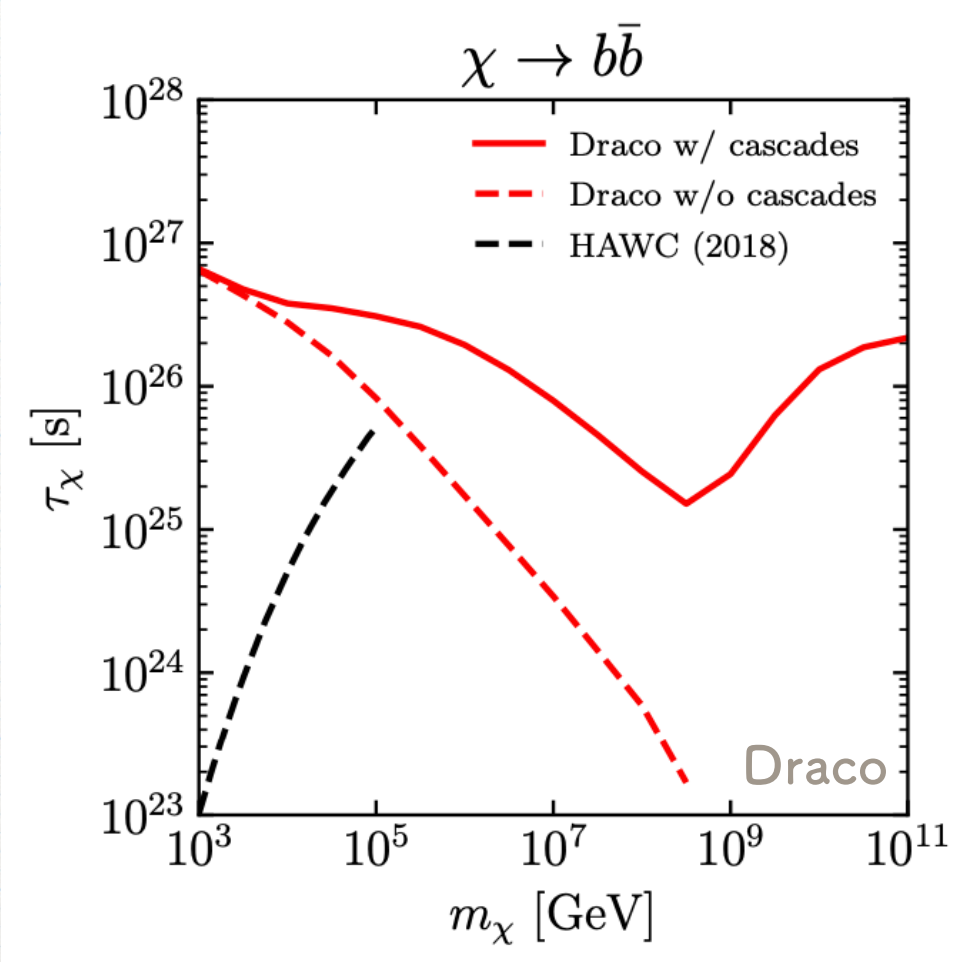
Fermi-LAT category II.5 paper

VHDM signals:

8 dSph stacked

Song, Hiroshima, Murase, 2024





leading limit for $\mathcal{O}(10^5)\mathrm{GeV} \lesssim m_{\mathrm{DM}} \lesssim \mathcal{O}(10^{11})\mathrm{GeV}$

dark matter particle

production of particle DM

a well-motivated mechanism: thermal freeze-out

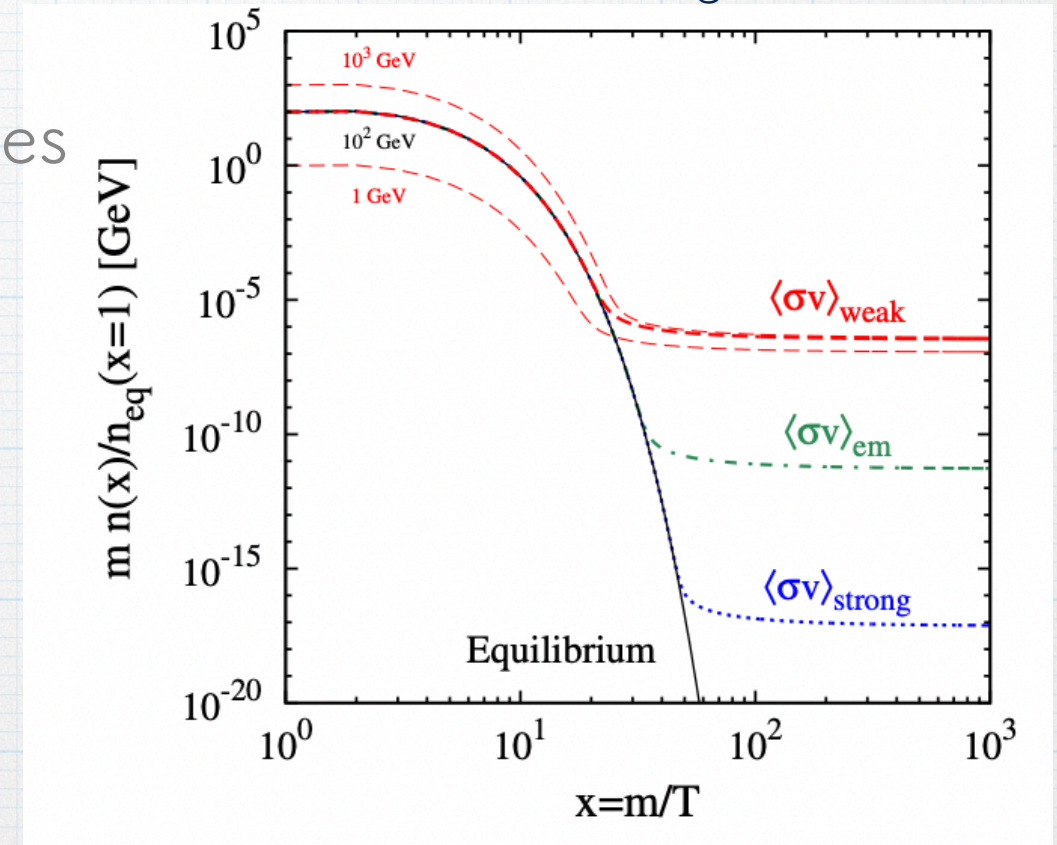
- similarity to the SM particles
- highly predictive
- benchmark

  $m_{\mathrm{DM}} \sim \mathcal{O}(\mathrm{MeV} - \mathrm{TeV})$

  $\langle \sigma v \rangle \sim \mathcal{O}(10^{-26}\mathrm{cm}^3/s)$

- nice particle realizations

Steigman et al., 2012



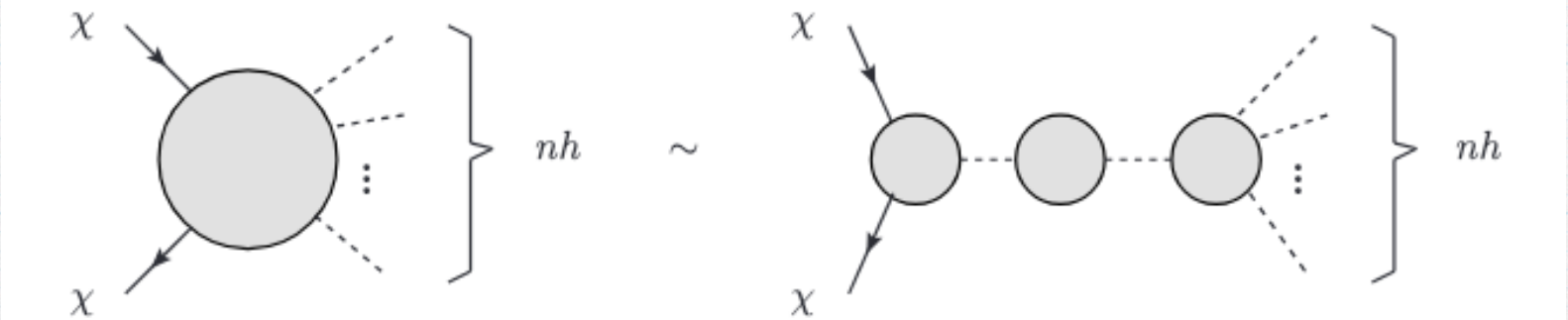
for VHDM:

over-abundance and the unitarity bound must be cared

what if DM+DM → hh?

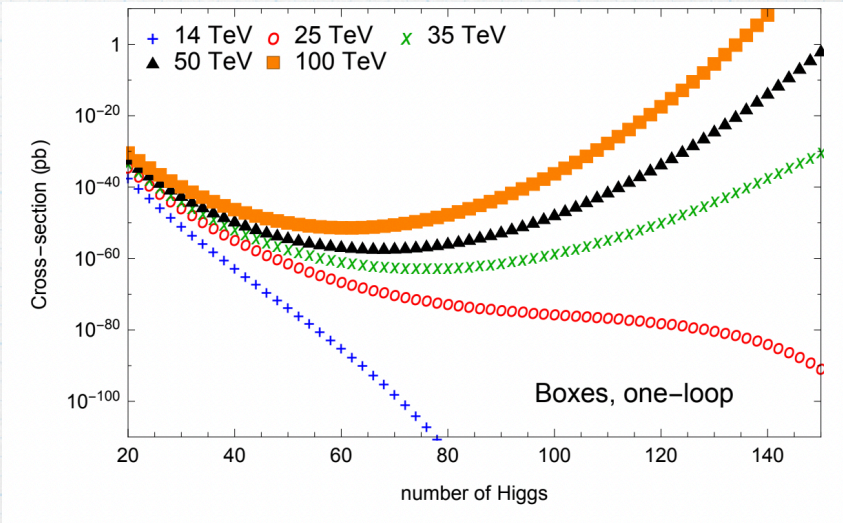
multiple Higgs production by self-interaction

Enomoto, Hiroshima, Murase, Yamanaka, in prep



- exponential growth of multiparticle process at high energy ("Higgsplosion")
- 2-to-2 → 2-to-n
- 2-to-n in intermediate state ("Higgspersion")

Khoze & Spannowski, 2017



modification to conventional thermal freeze-out

Higgs-portal heavy DM

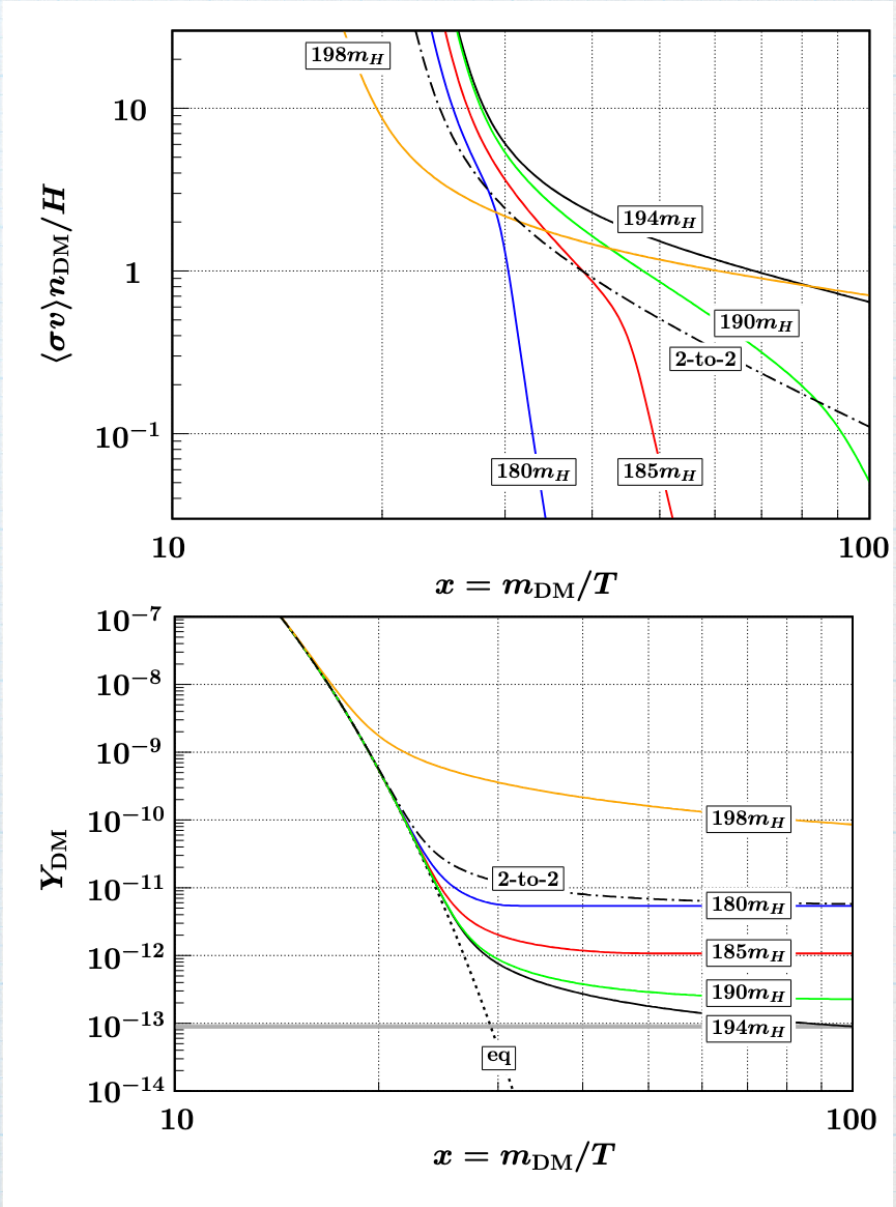
Enomoto, Hiroshima, Murase, Yamanaka, in prep

- balance between "Higgsplosion" and "Higgspersion"
- overproduction can be avoided by maintaining thermal equilibrium longer

relic abundance achieved with Higgs-portal DM,

$m_{\rm DM} = 4.85$ TeV,

λ=0.129, n=194



Summary

- Halo is a key to access the nature of DM and also serve as important indicators in cosmology.
- Properties of dwarf satellites as galaxies in subhalos helps to improve analysis of DM signals.
- Connections between DM and the Standard Model sector can be revised by go deep inside the particle physics and cosmology.

Everything is intertwined.