Why does the Universe accelerate?
-Exhaustive study and challenge for the future, 2019.3.3

# Modeling Evolution of Dark Matter Substructure and Annihilation Boost

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公募研究「ガンマ線と大規模構造のクロス相関による暗黒物質粒子の探査」
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# Motivations

# WIMP dark matter

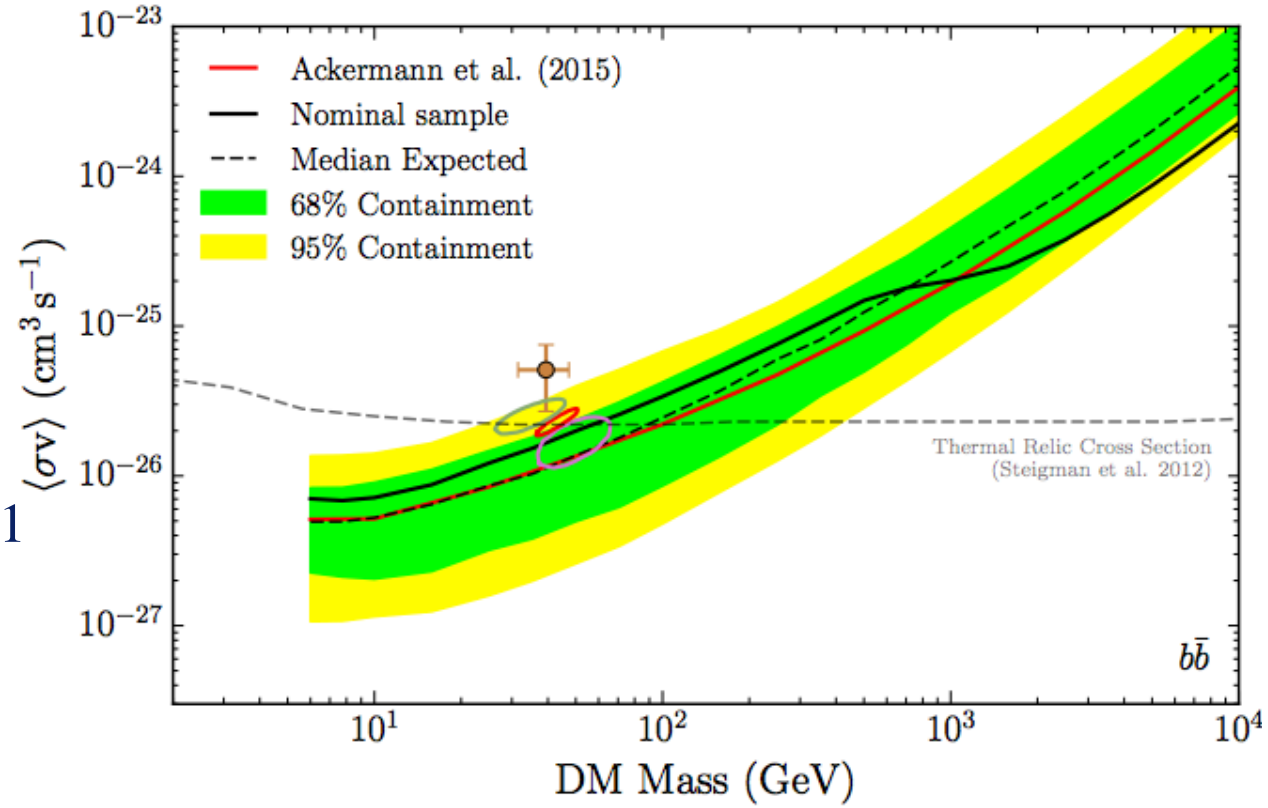
- Naturally explains the relic abundance with the canonical cross-section

$$\langle \sigma v \rangle \sim 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}$$

- WIMP DM mass should be

$$m_{\mathrm{DM}} \sim \mathcal{O}(1)\mathrm{GeV} - \mathcal{O}(1)\mathrm{TeV}$$

The Fermi-LAT, DES collaboration, 2016



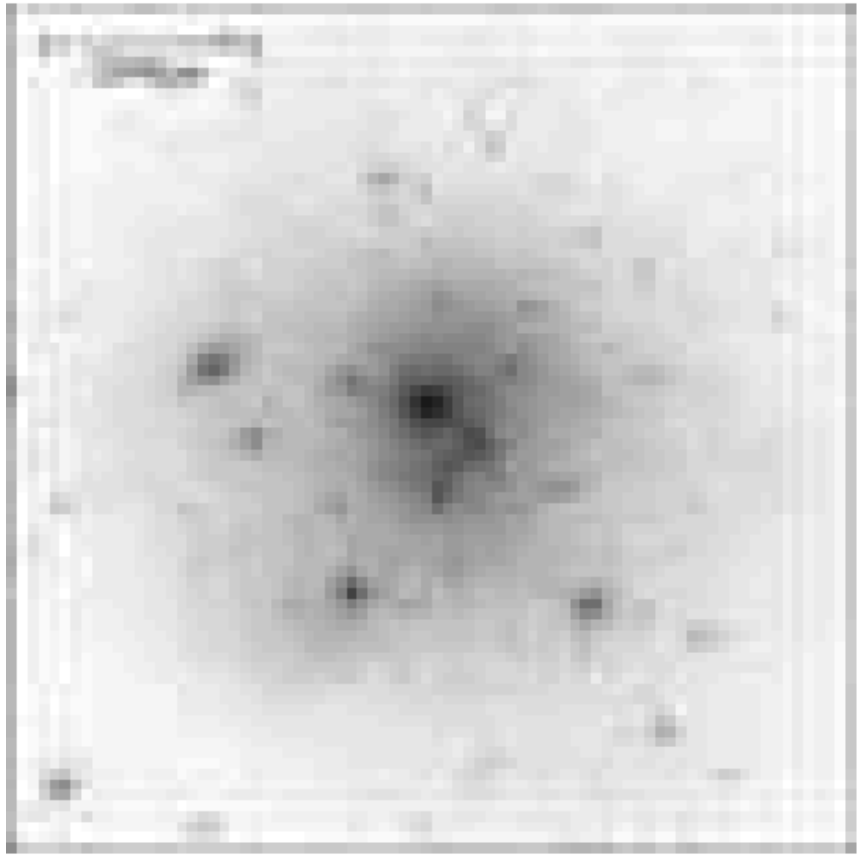

- Gamma-ray observations are important.

**Only two model parameters.**

# Subhalo in WIMP scenario

- WIMP scenario predict formation of small scale structures down to $10^{-12} - 10^{-3} M_{\odot}$
- They should reside in larger halos (i.e.,"subhalos").

Ishiyama, Fukushige, Makino, 2008

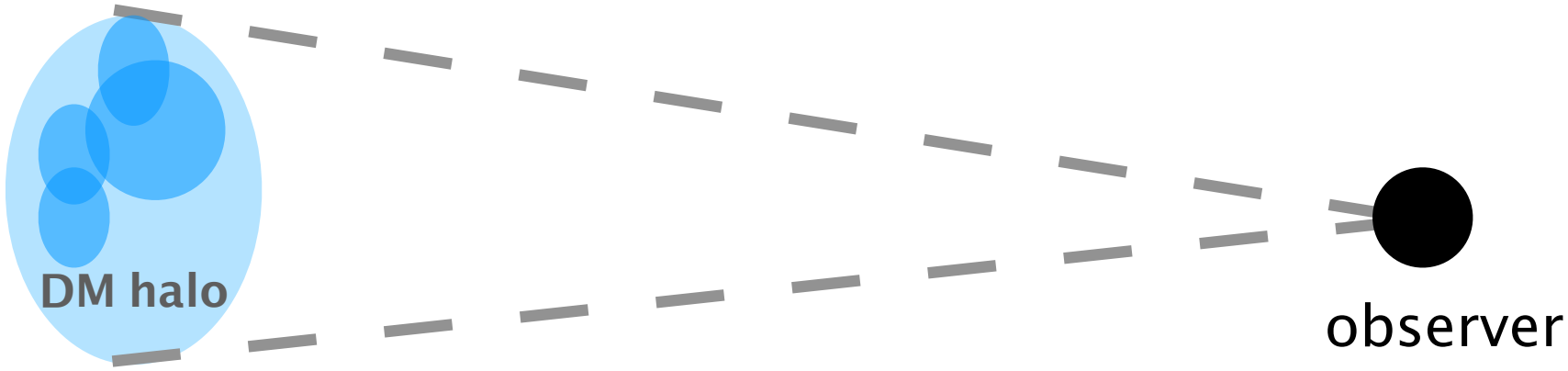


**The existence of subhalos is expected.**

# The importance of subhalo

1. Subhalos contains information about the property of DM.

2. Subhalos on our lines-of-sight enhance the DM annihilation signal (boost factor):

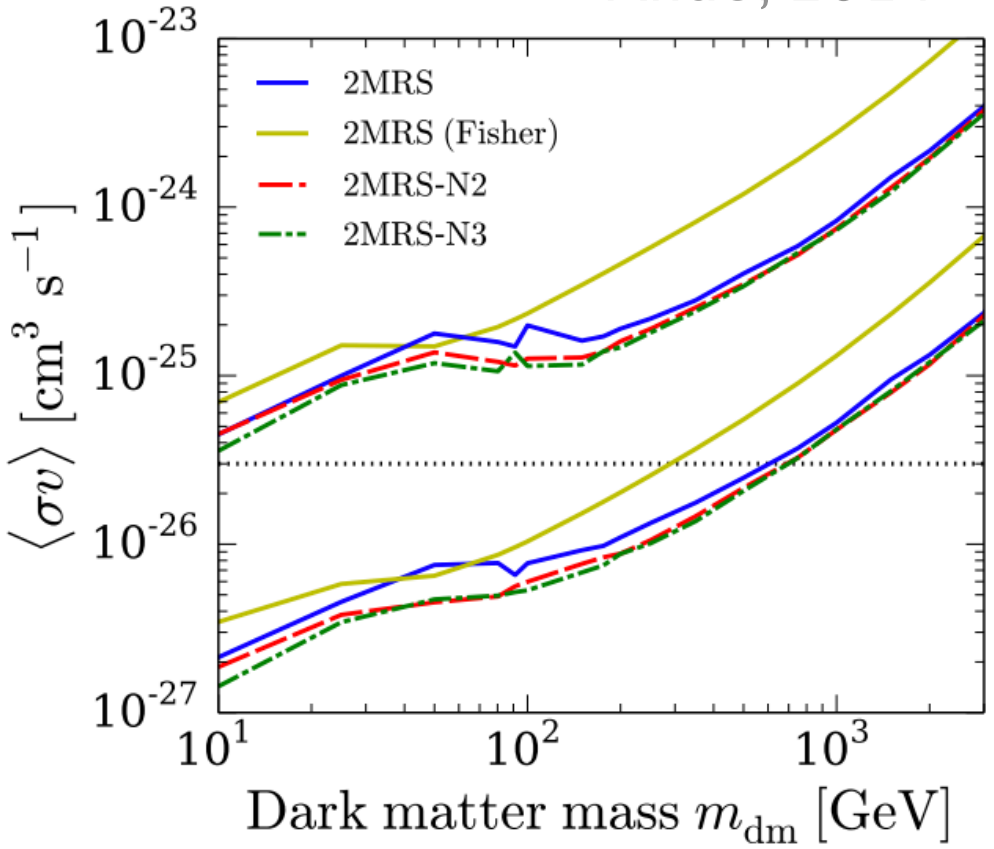



$$\phi_\gamma = \frac{1}{2}\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{m_{\rm DM}^2}\int\frac{dN_\gamma}{dE_\gamma}dE_\gamma \cdot (1+\mathrm{B})\int_{l.o.s}\rho_{\rm DM}^2 ds$$

# DM search using cross-correlation

- The DM distribution should trace that of the galaxy
- Cross-correlation with nearby galaxies is an efficient probe.
- The constraints differ by a factor of $\gtrsim 10$ depending on the boost models.

Ando, Benoit-Levy, Komatsu 2013
Ando, 2014




**We need to quantify the subhalo boost.**

# Estimates of subhalo boost

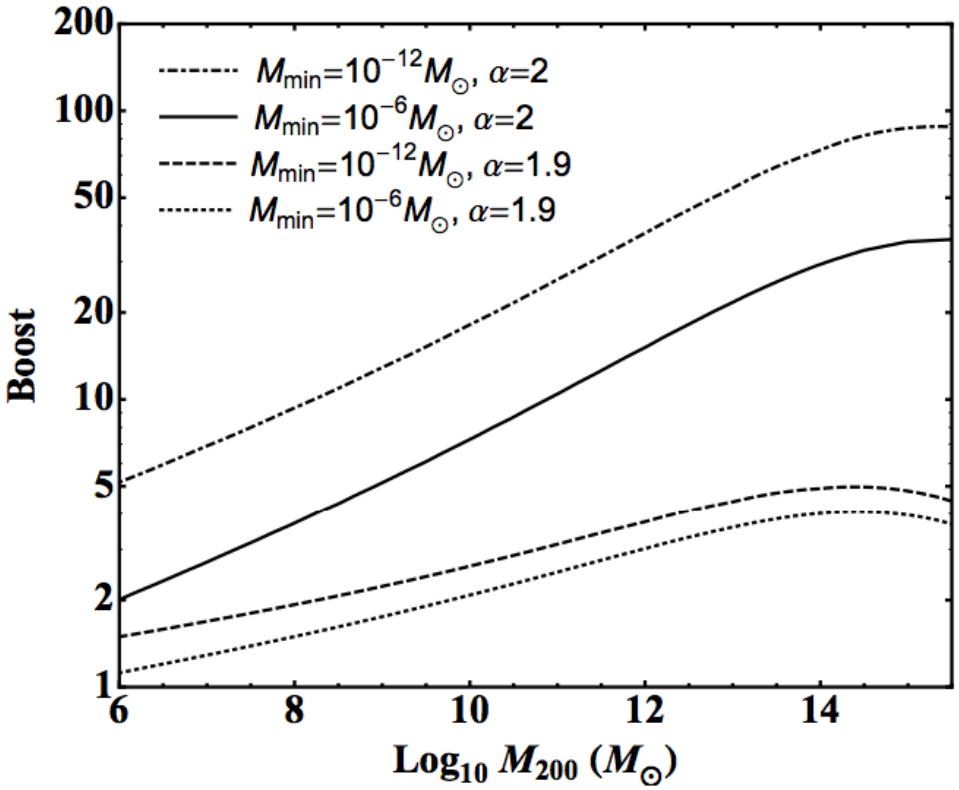
We need to cover

- $M_{\rm halo} \sim 10^{-6} - 10^{16} M_\odot$
- $z \sim 0 - 10$

Previous works adopted extrapolation of results from numerical simulations:

mass function $\dfrac{dN}{dm} \propto m^{-\alpha}$

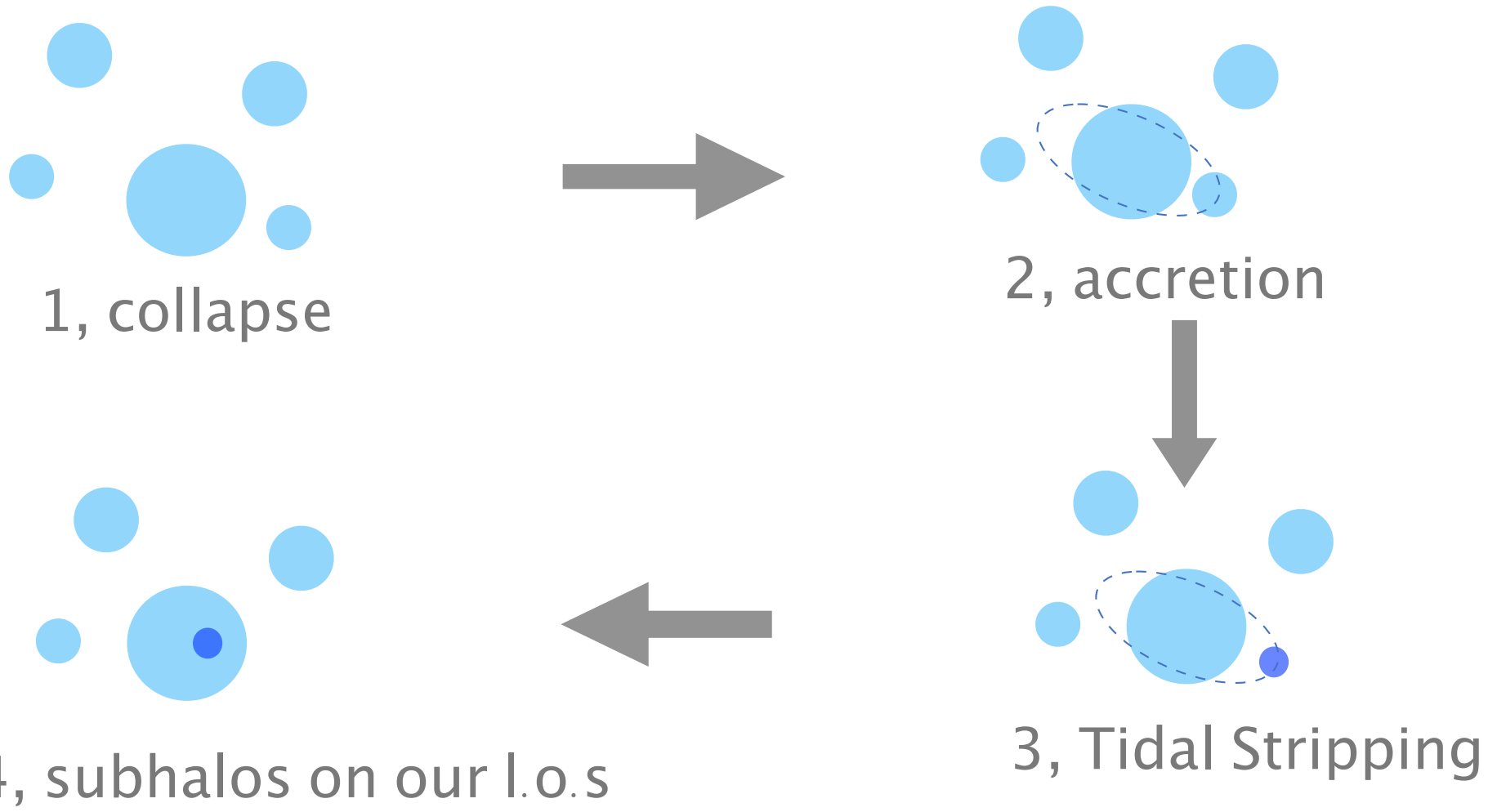
Sanchez-Conde & Prada, 2013




**We have developed a new analytical formalism!**

# Analytical Modeling

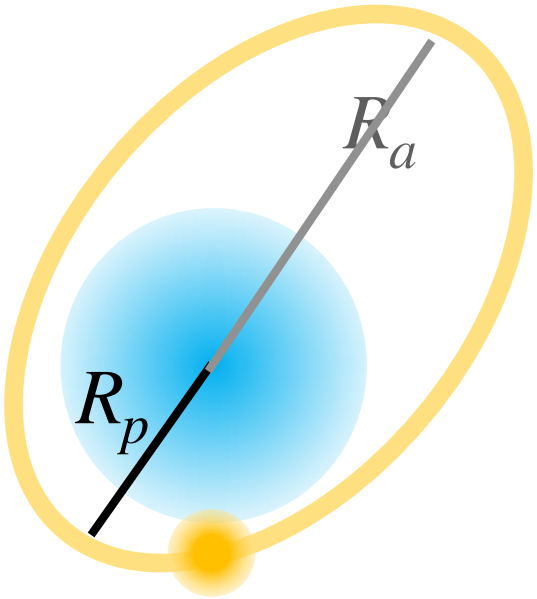
# The situation



# Evolution of subhalos

1. Formation
2. Accretion

EPS formalism



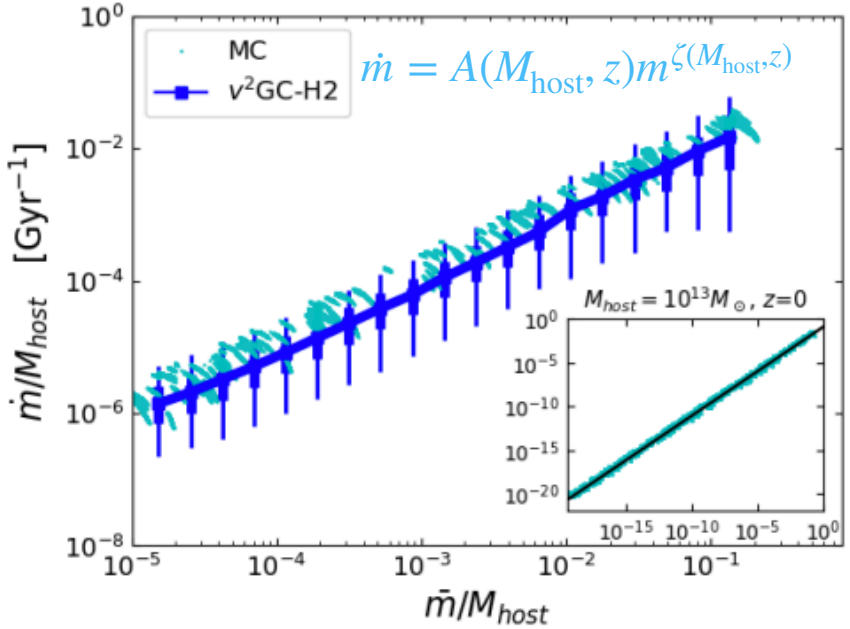

3. Tidal Stripping

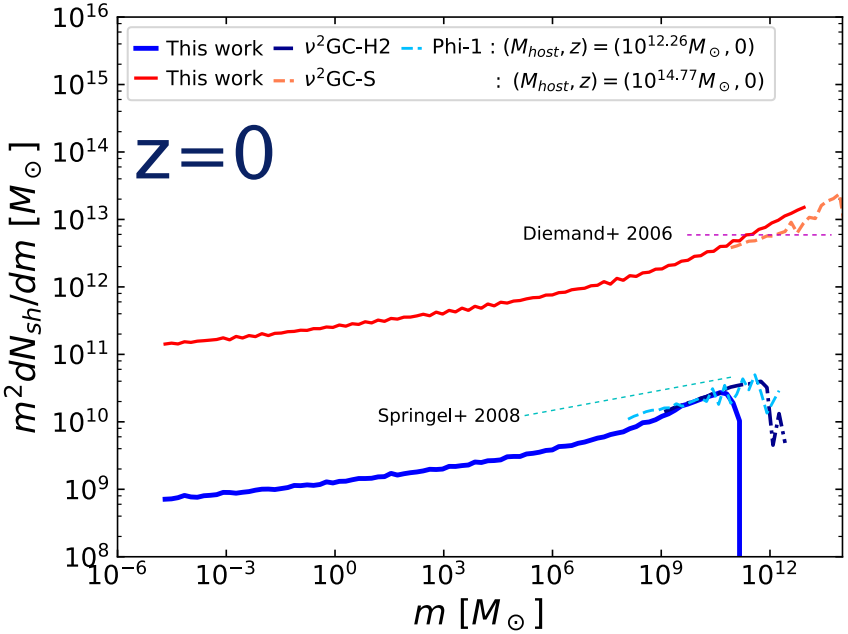
Assumptions:

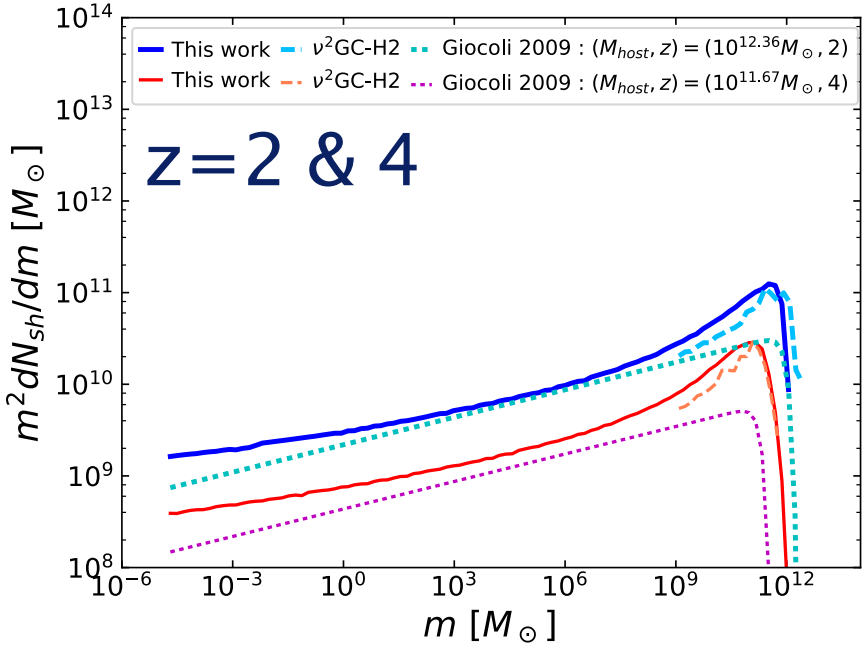
- NFW profile with truncation for host & subhalo
- mass-loss occurs in the first orbit of each subhalo

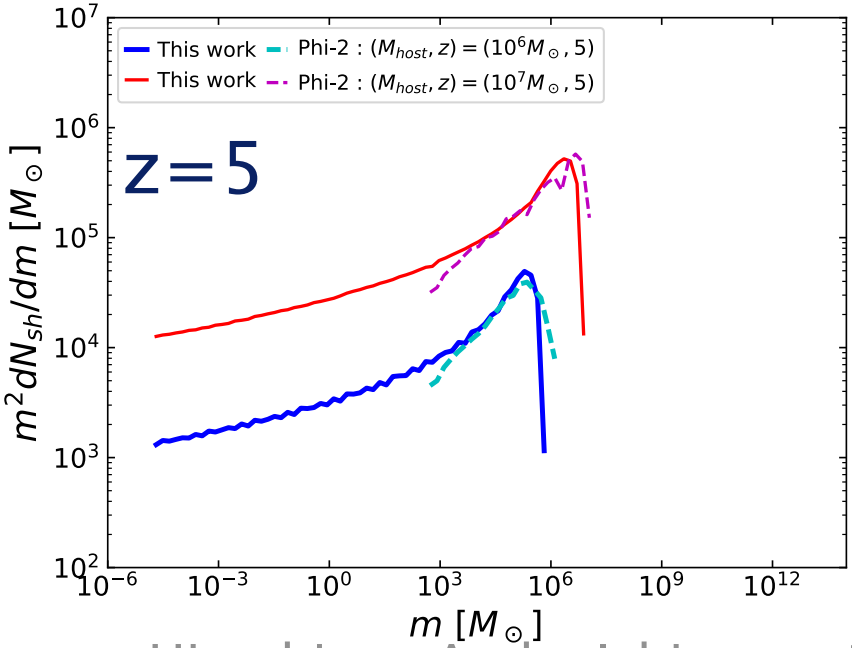
$$\dot{m} = \frac{m - m(r_t)}{T_r}$$

# The power of analytical calculations



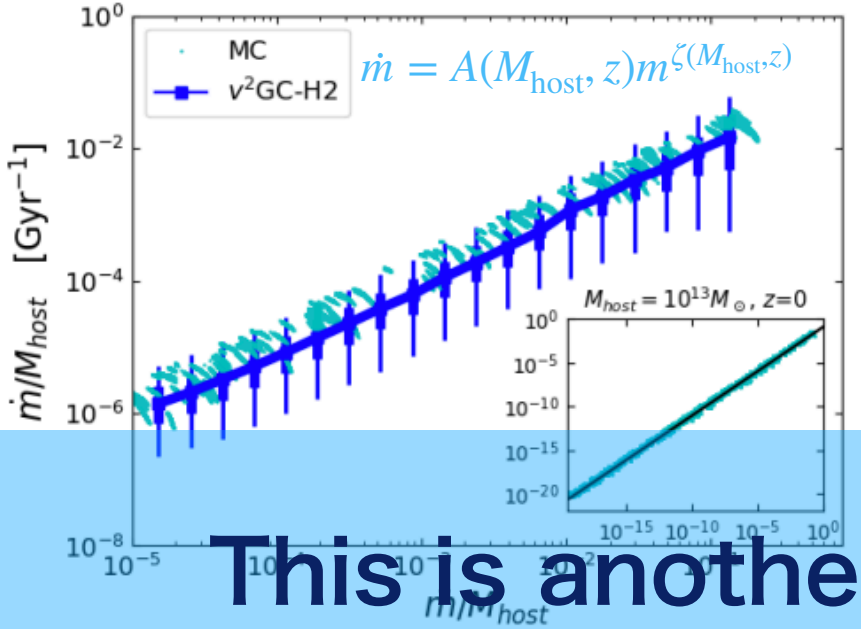



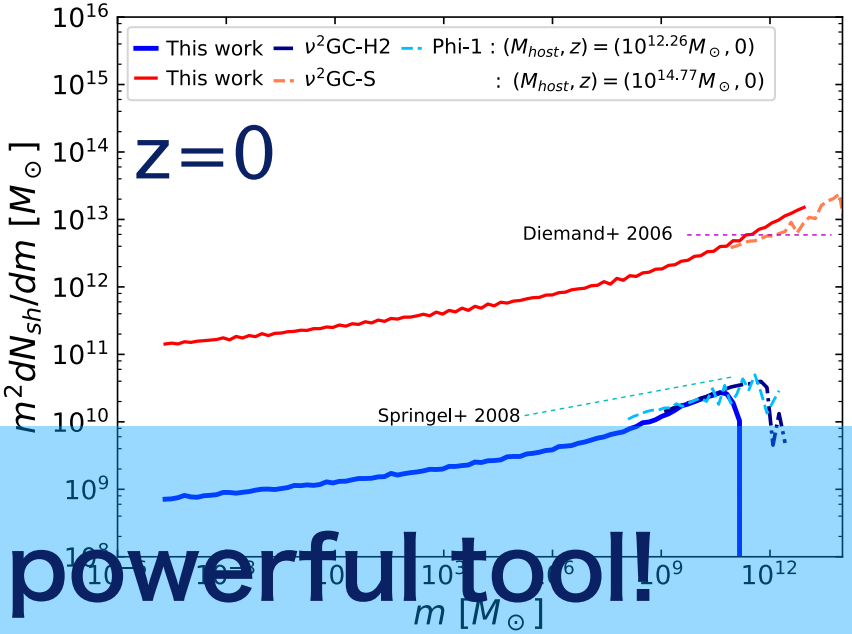





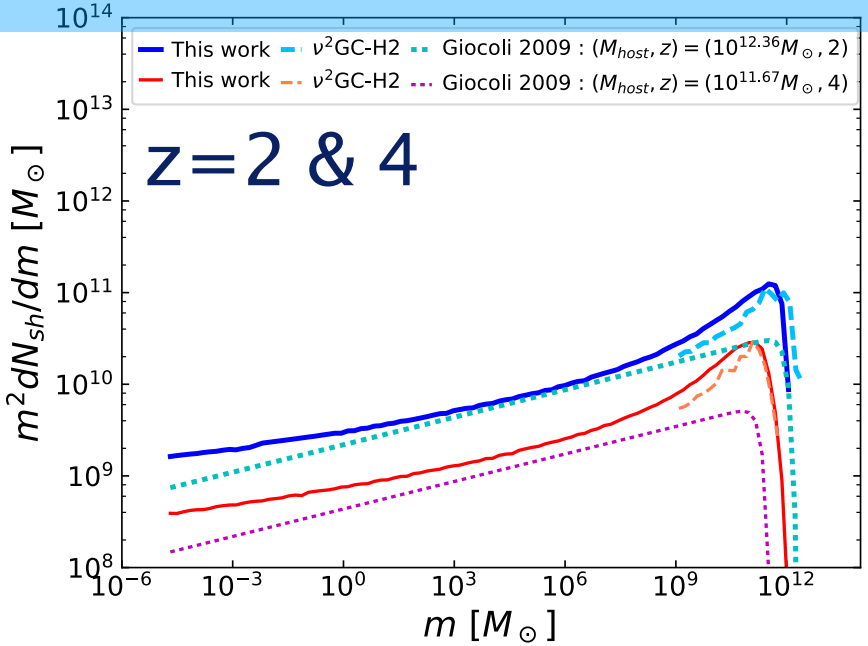

Hiroshima, Ando, Ishiyama, 2018

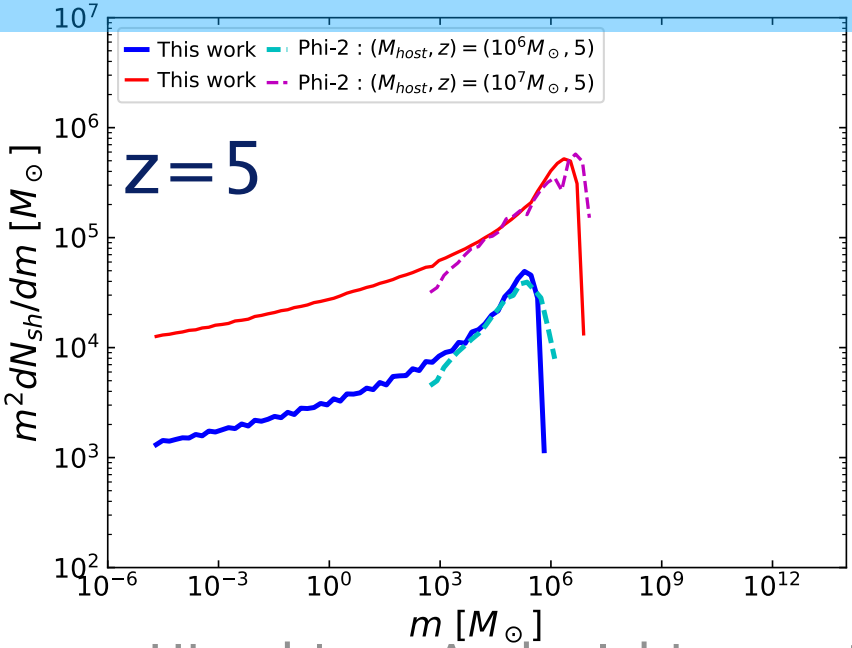
# The power of analytical calculations




**This is another powerful tool!**

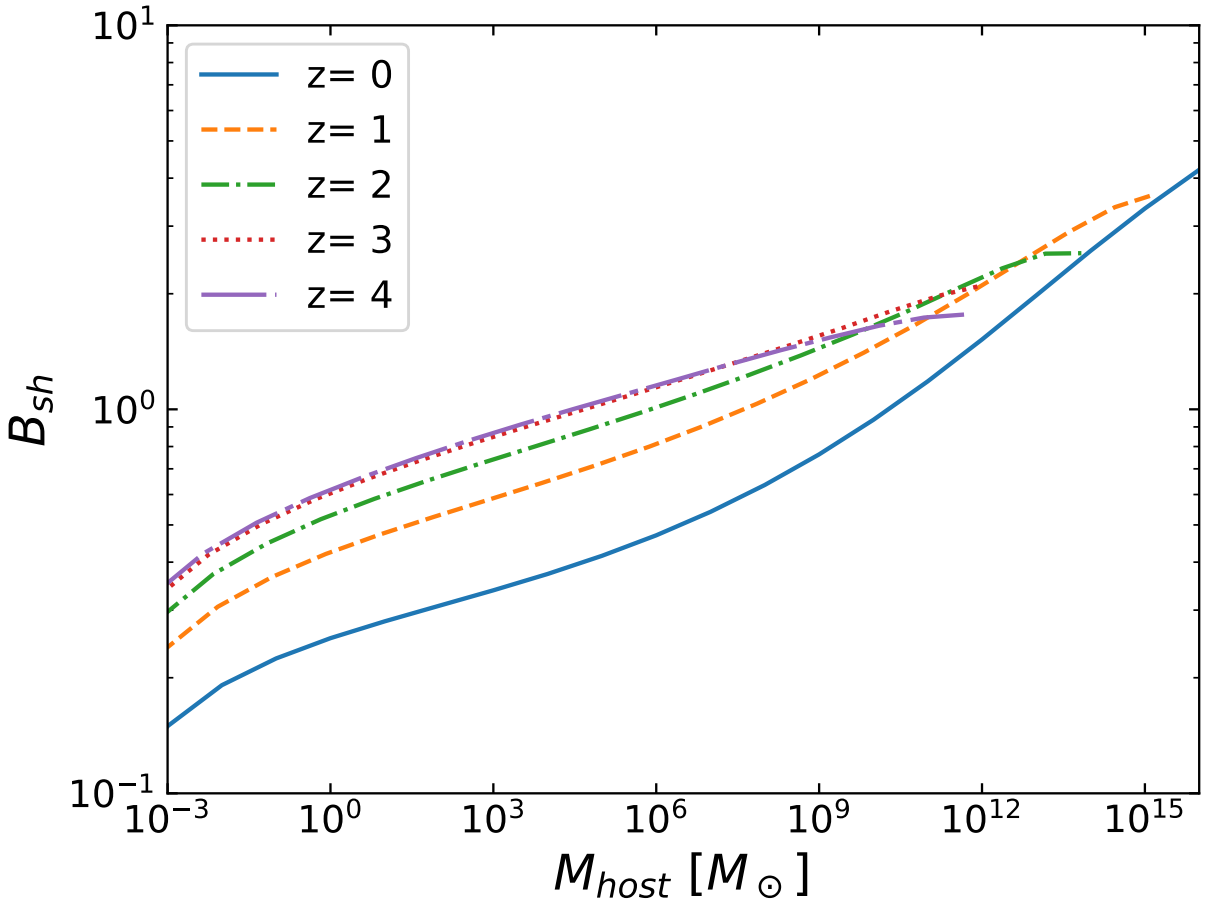




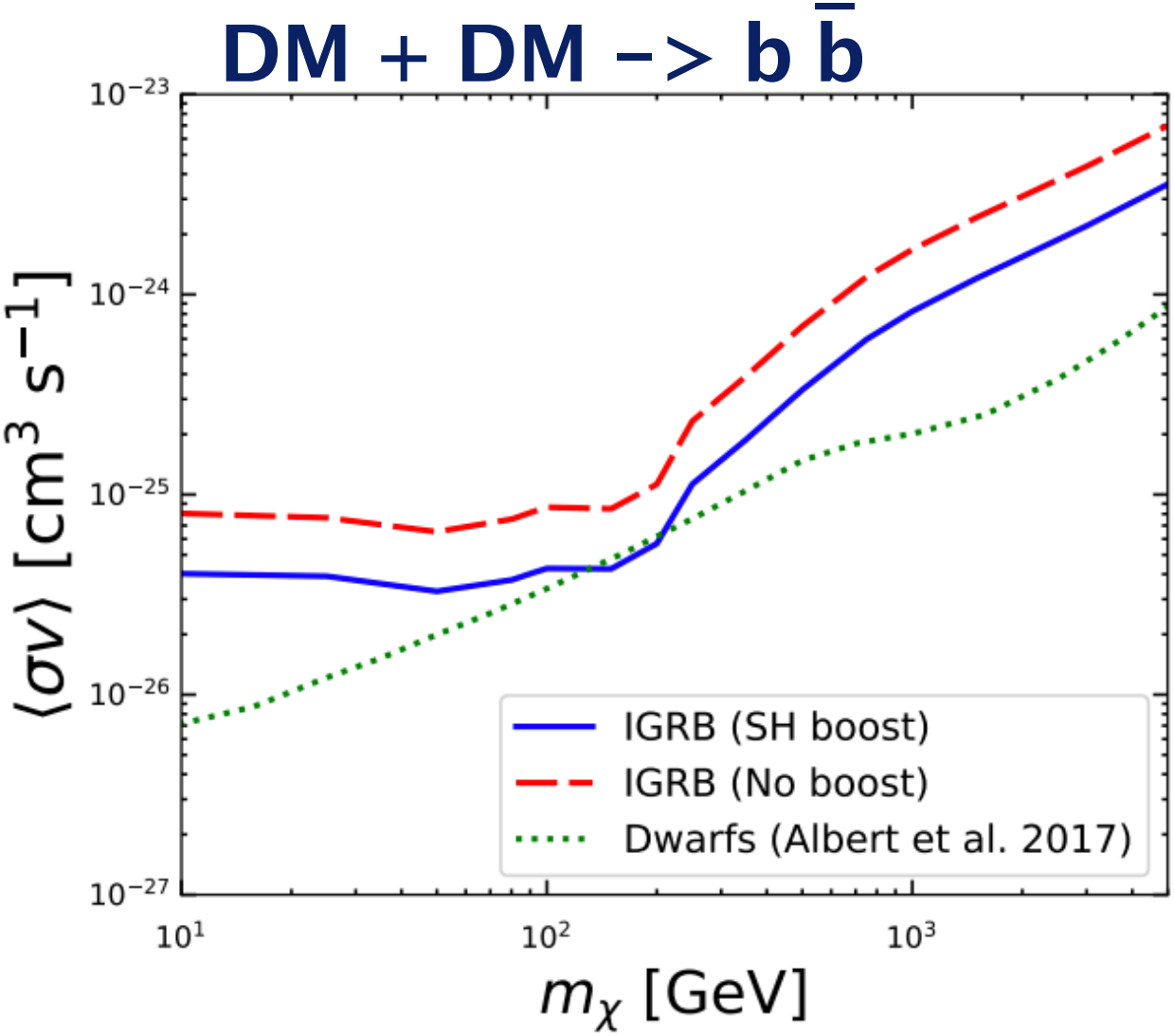

Hiroshima, Ando, Ishiyama, 2018

# Boost Factor




**Annihilation signal is boosted by factors**

# Update on IGRB limit

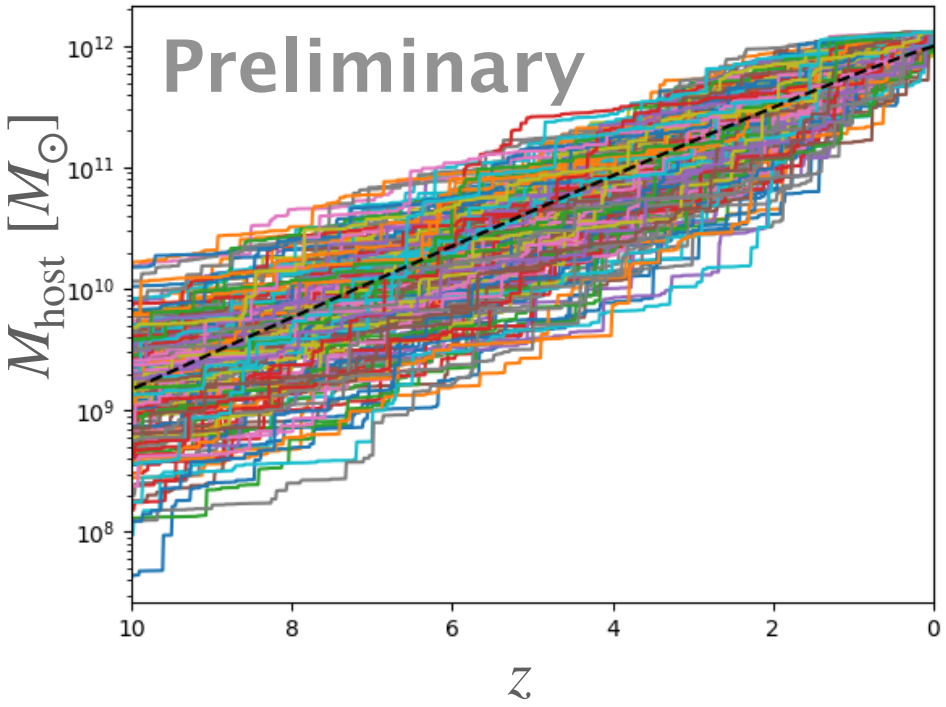



**Improving IGRB constraint**

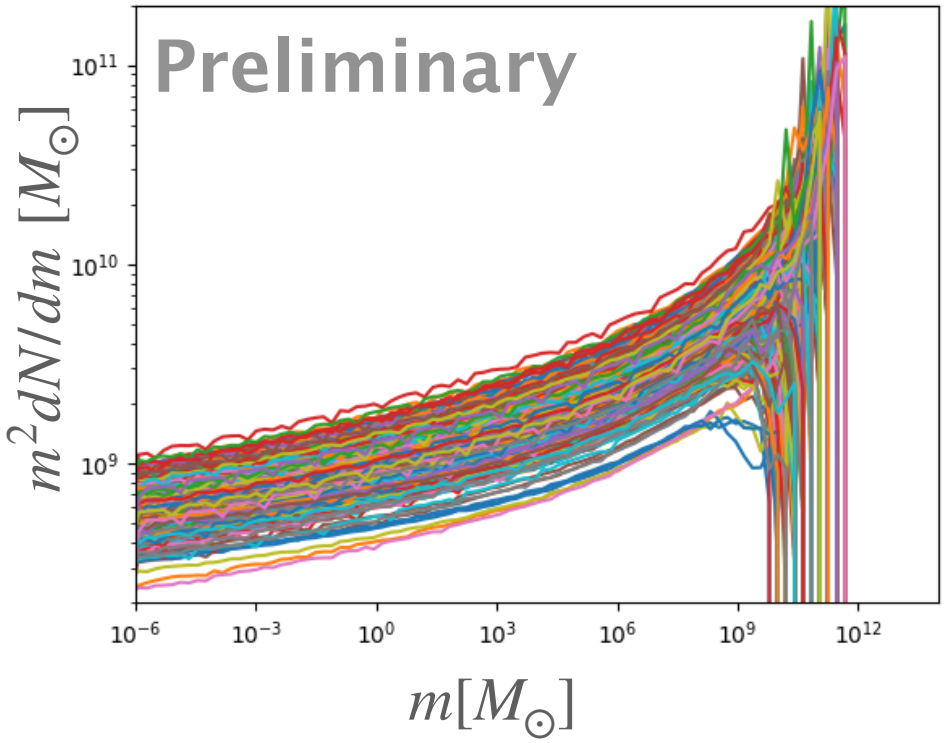
# Extensions & Summary

# Implementation of the halo-to-halo scatter

evolution of the host




mass function




**We can address many issues:**

- **too-big-to-fail problem**
- **microhalo search with PTA (Kashiyama & Oguri 2018)**
- **…**

# Summary

- **Precise understanding about the subhalo is important to search particle DM.**
- **We have developed an analytical formalism to follow the evolution of subhalos. The results agrees well with those of N-body calculations.**
- **DM annihilation signals can be boosted up to a factor of 10 in cluster scales**
- **We are now working on the further update to implement the halo-to-halo scatter.**