Looking for Dark Matter Substructure from The Stone Age

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MIT, Aug 28

Introduction

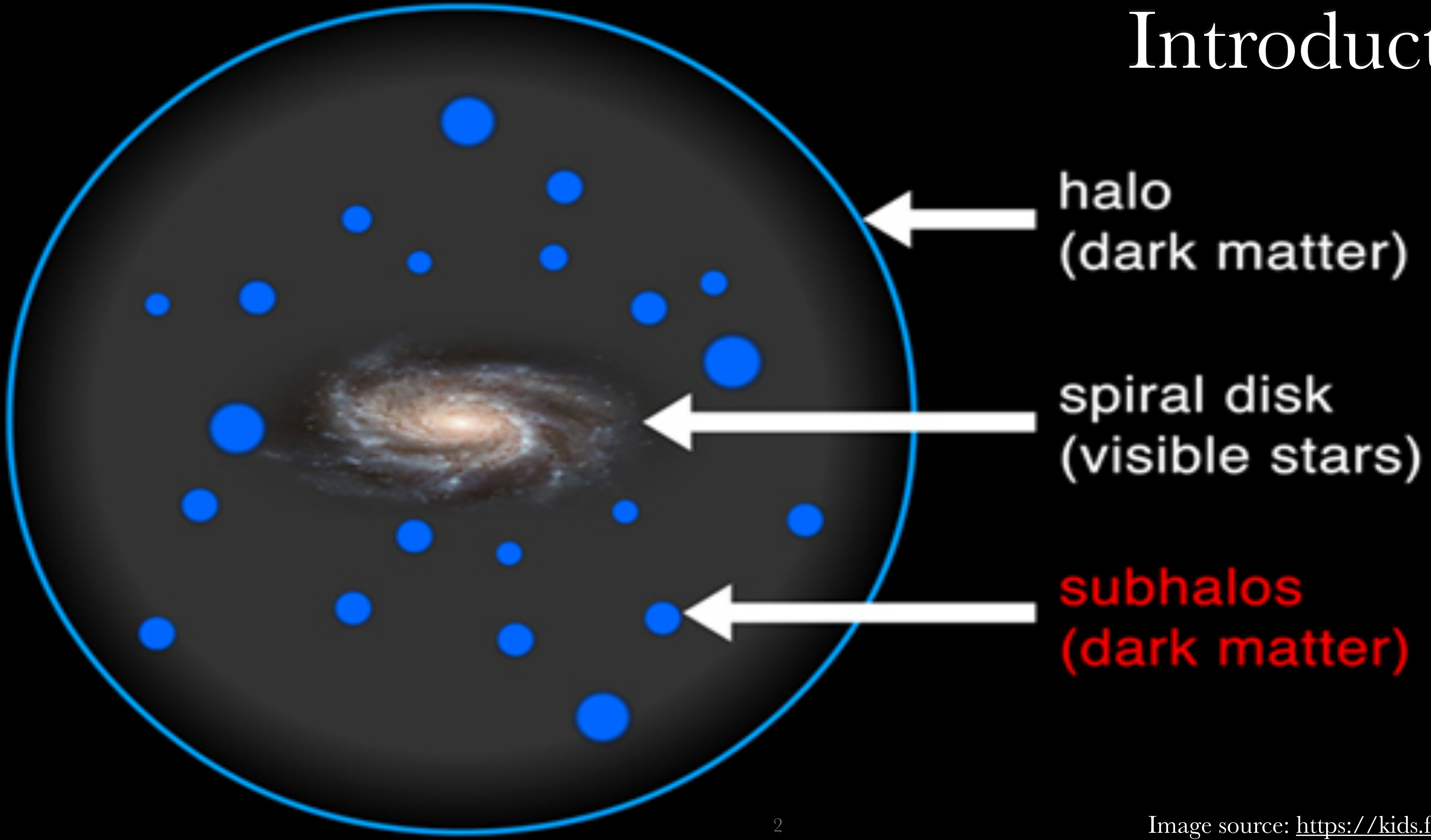


Image source: https://kids.frontiersin.org/

Introduction

Subhalo Encountering Rate

- $\frac{dR_{sub}}{dM_{sub}} = \int \frac{dn_{sub}}{dM_{sub}} f(v) v \sigma(v, M_{sub}) dv$

- $\frac{dR_{sub}}{dM_{sub}}$ is the differential rate of subhalo encountering events in unit of counts per year per solar mass

- $\frac{dn_{sub}}{dM_{sub}}$ is the local differential number density of subhalos in unit of number of subhalos per pc^3 per solar mass

- $f(v)$ is the velocity distribution of subhalos

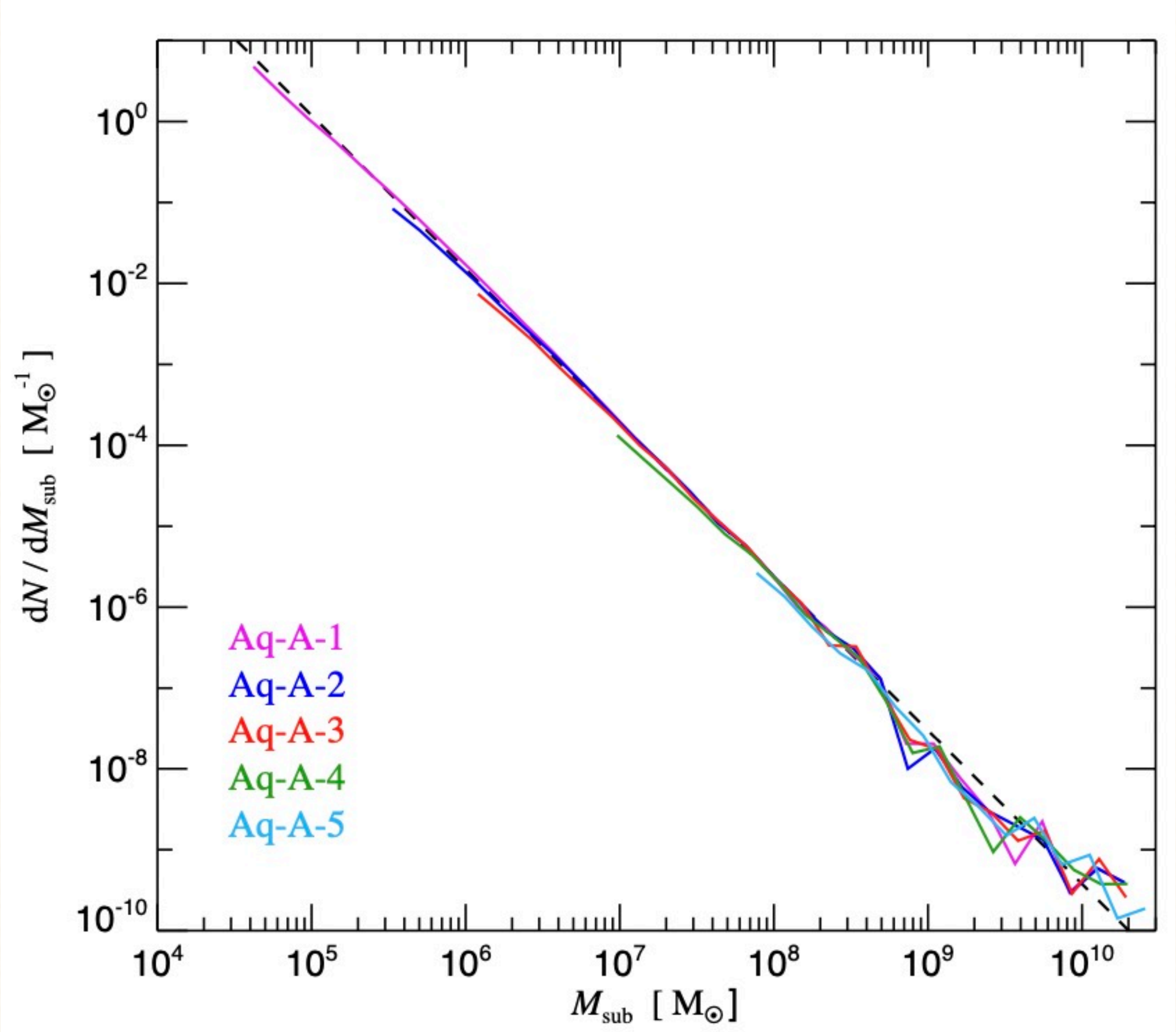
- σ is the cross-section for the encountering event

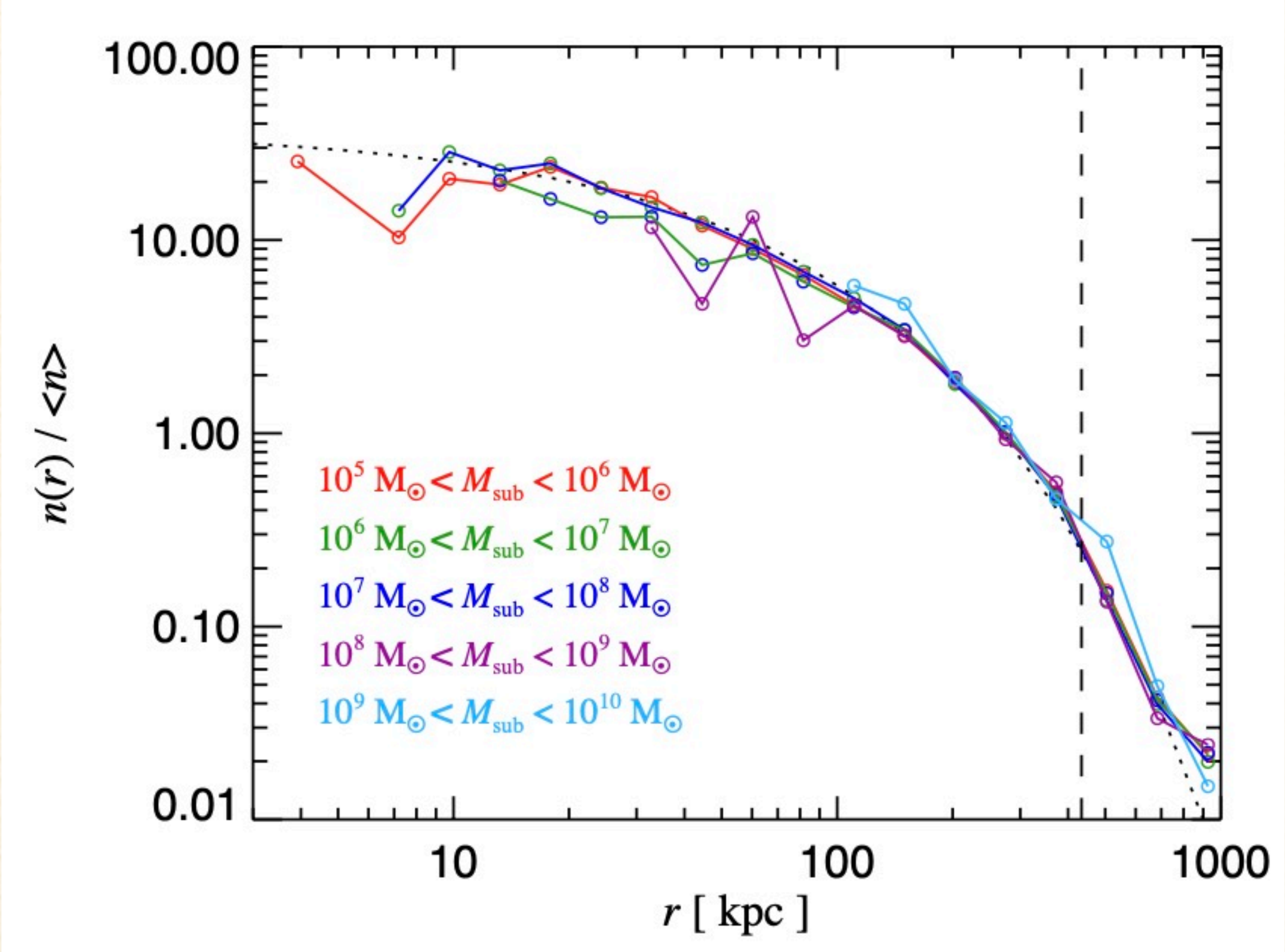
Local Differential Number Density

$$\frac{dR_{sub}}{dM_{sub}} = \int \frac{dn_{sub}}{dM_{sub}} f(v) v \sigma(v, M_{sub}) dv$$

$$\frac{dN_{sub}}{dM_{sub}} = a_0 \left(\frac{M_{sub}}{m_0} \right)^{\beta}$$

$$n_{sub} \propto exp[-\frac{2}{\alpha} \left(\left(\frac{r}{r_{-2}} \right)^{\alpha} - 1 \right)]$$





Springel et al, 0809.0898

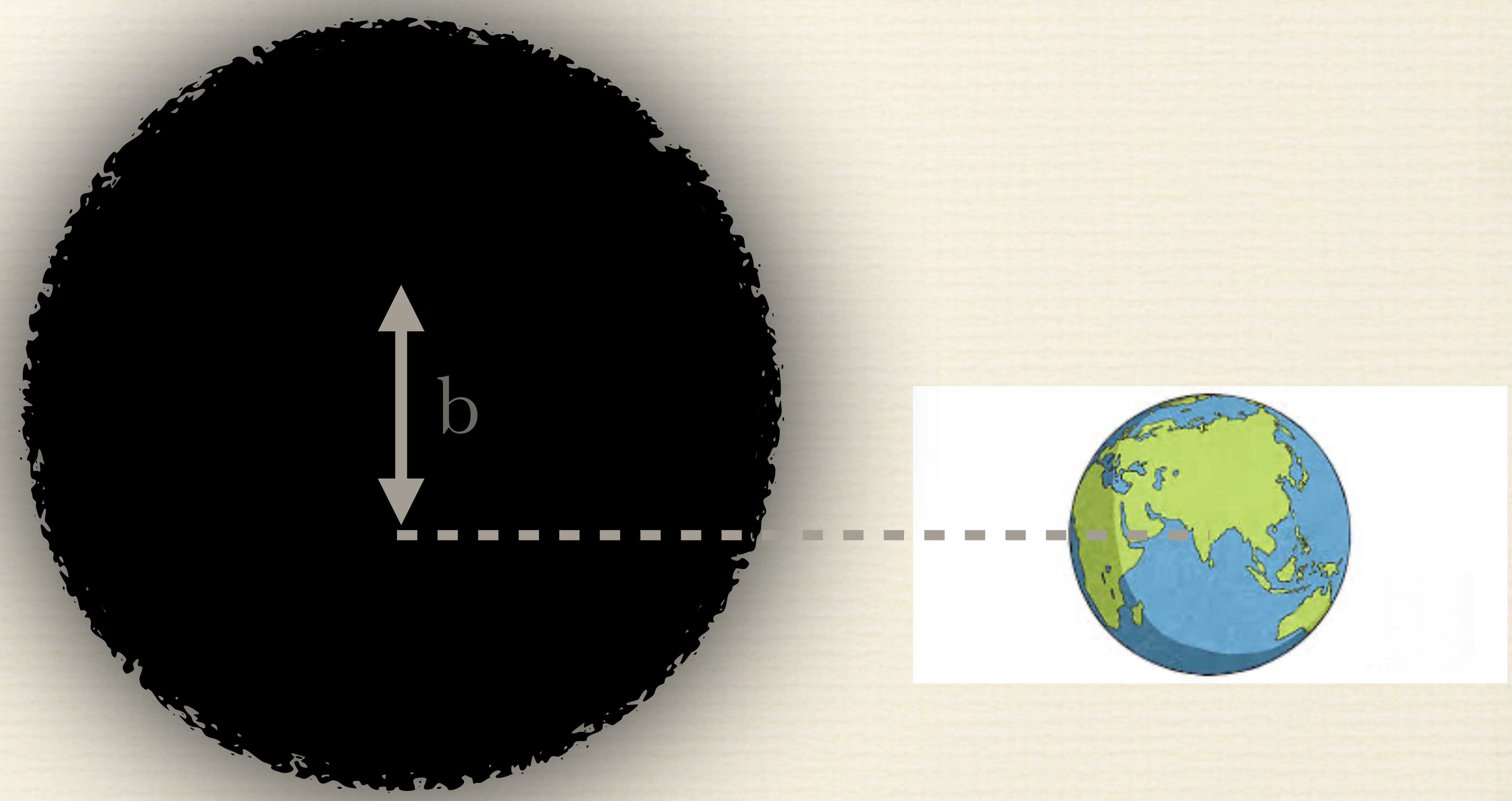
Encounter Cross-section

$$\frac{dR_{sub}}{dM_{sub}} = \int \frac{dn_{sub}}{dM_{sub}} f(v) v \sigma(v, M_{sub}) dv$$

- Cross-section:

$$\sigma = \int_0^{2\pi} d\phi \int_0^{b_{max}} b db = \pi b_{max}^2$$

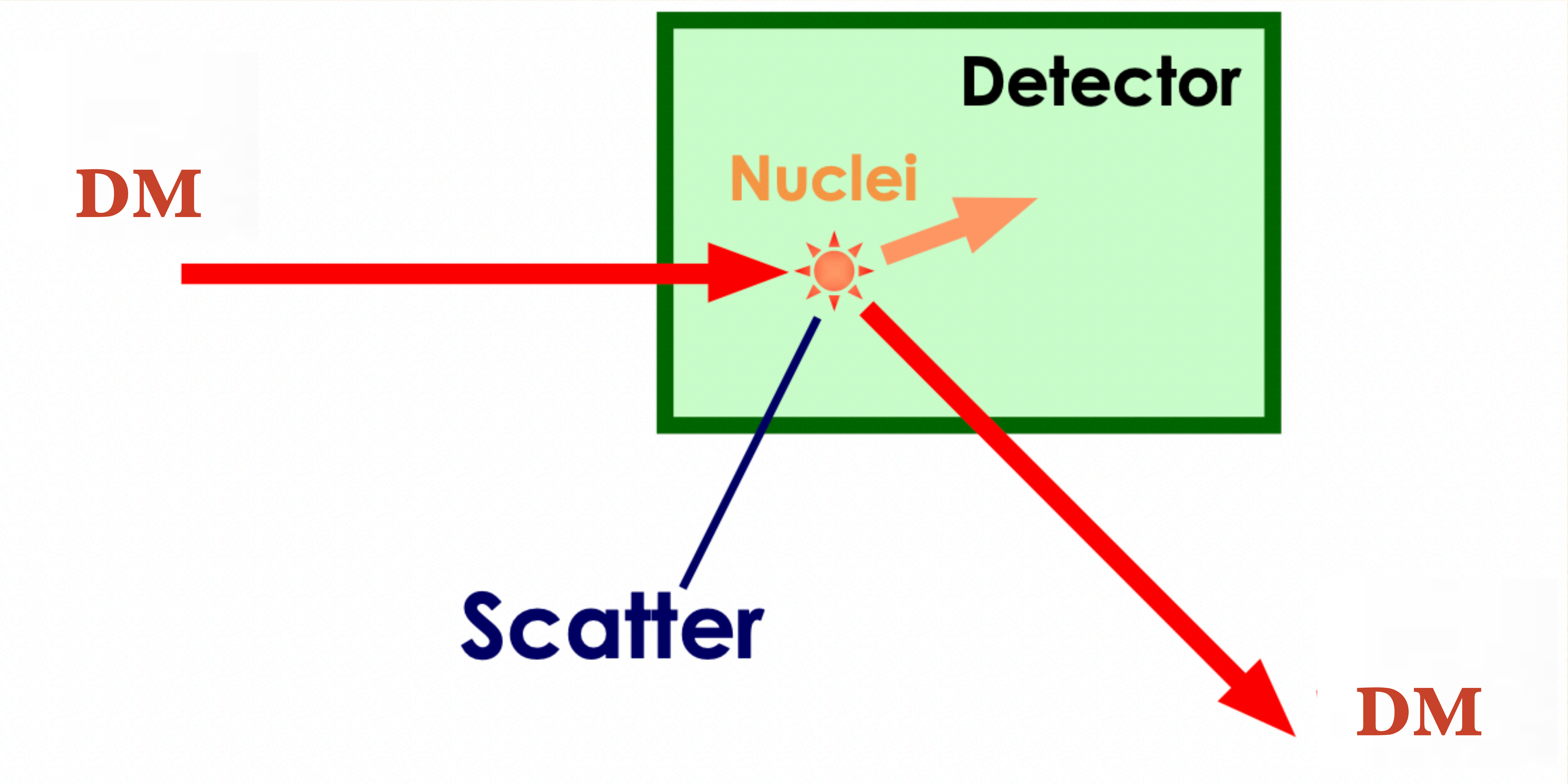
- b_{max} is the maximum impact parameter such that the closest approach point of the subhalo has a density higher than the local dark matter density $0.3 GeV/cm^3$

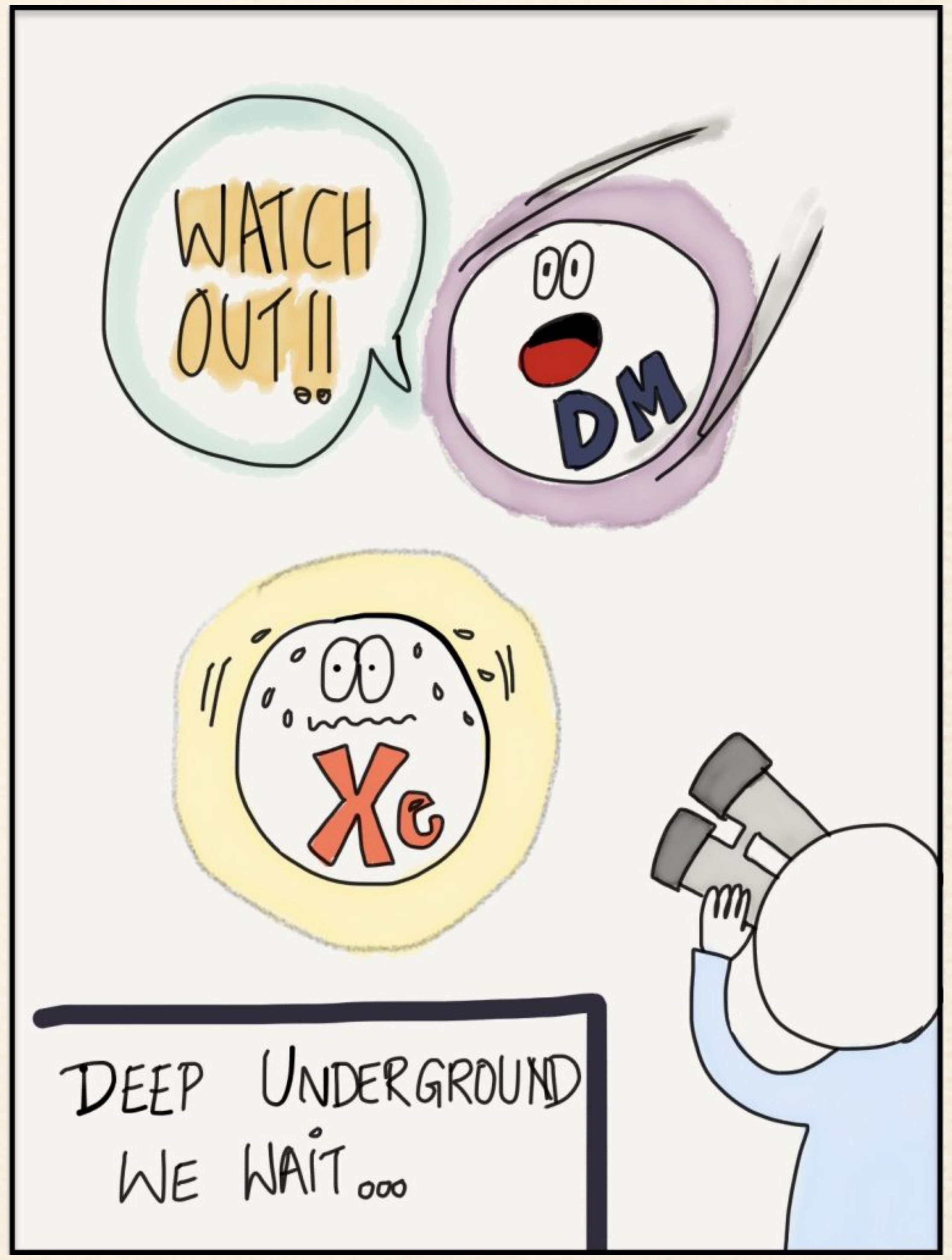


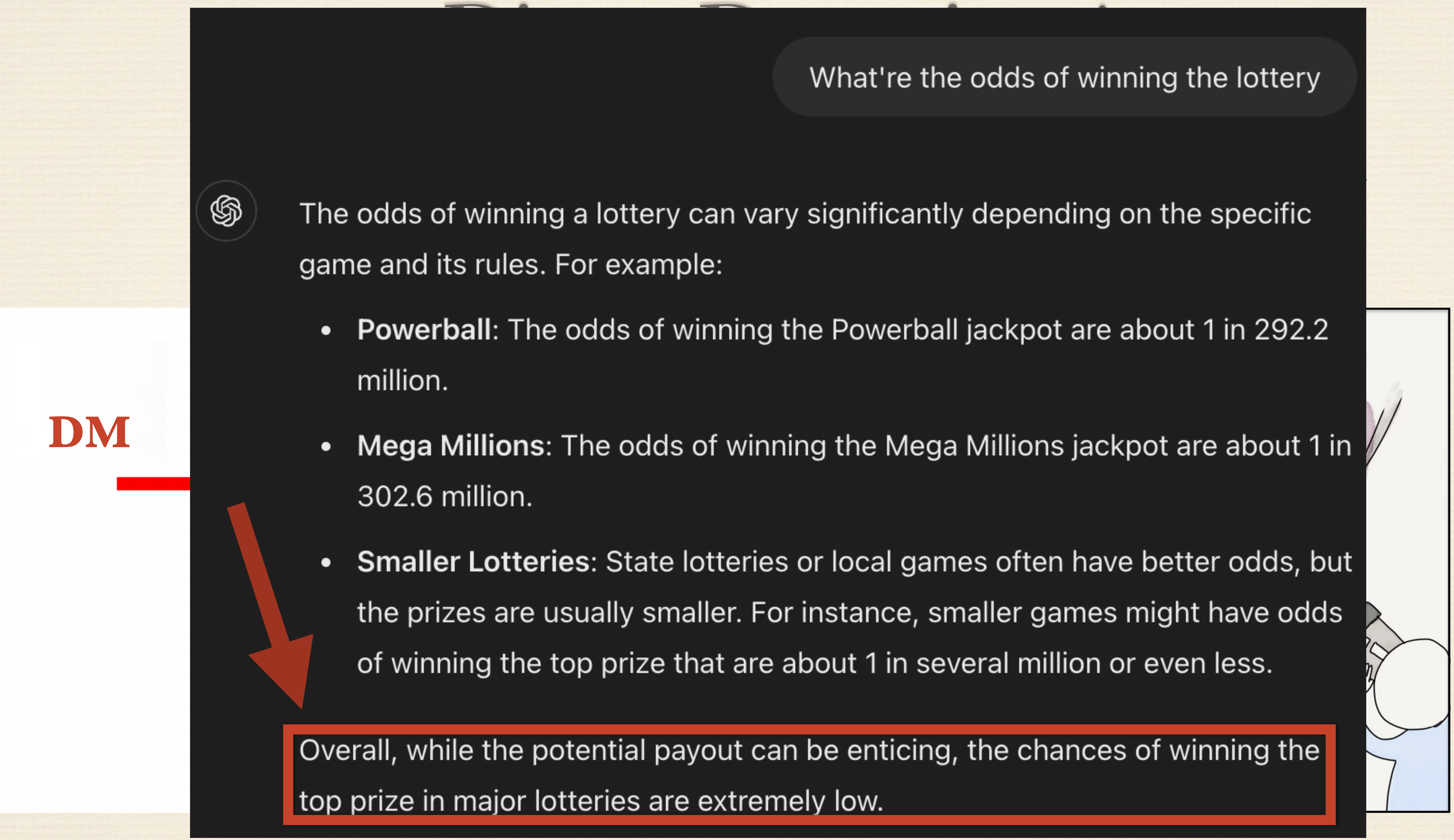
Direct Detections!

- The number of subhalos hitting us per year is …

$$1.5 \times 10^{-9}!!!$$

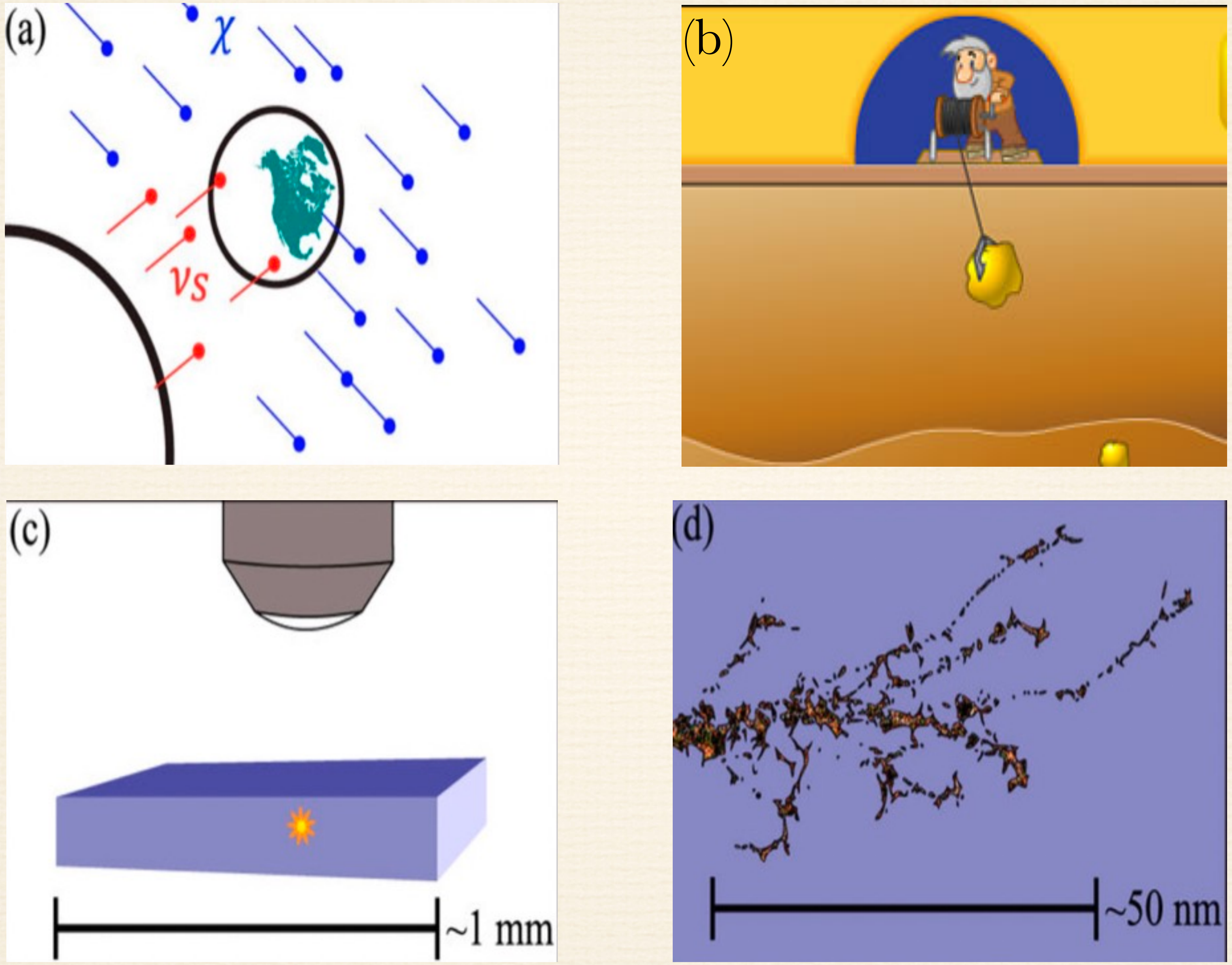





DM
What're the odds of winning the lottery
The odds of winning a lottery can vary significantly depending on the specific game and its rules. For example:
Powerball: The odds of winning the Powerball jackpot are about 1 in 292.2 million.
Mega Millions: The odds of winning the Mega Millions jackpot are about 1 in 302.6 million.
Smaller Lotteries: State lotteries or local games often have better odds, but the prizes are usually smaller. For instance, smaller games might have odds of winning the top prize that are about 1 in several million or even less.
Overall, while the potential payout can be enticing, the chances of winning the top prize in major lotteries are extremely low.

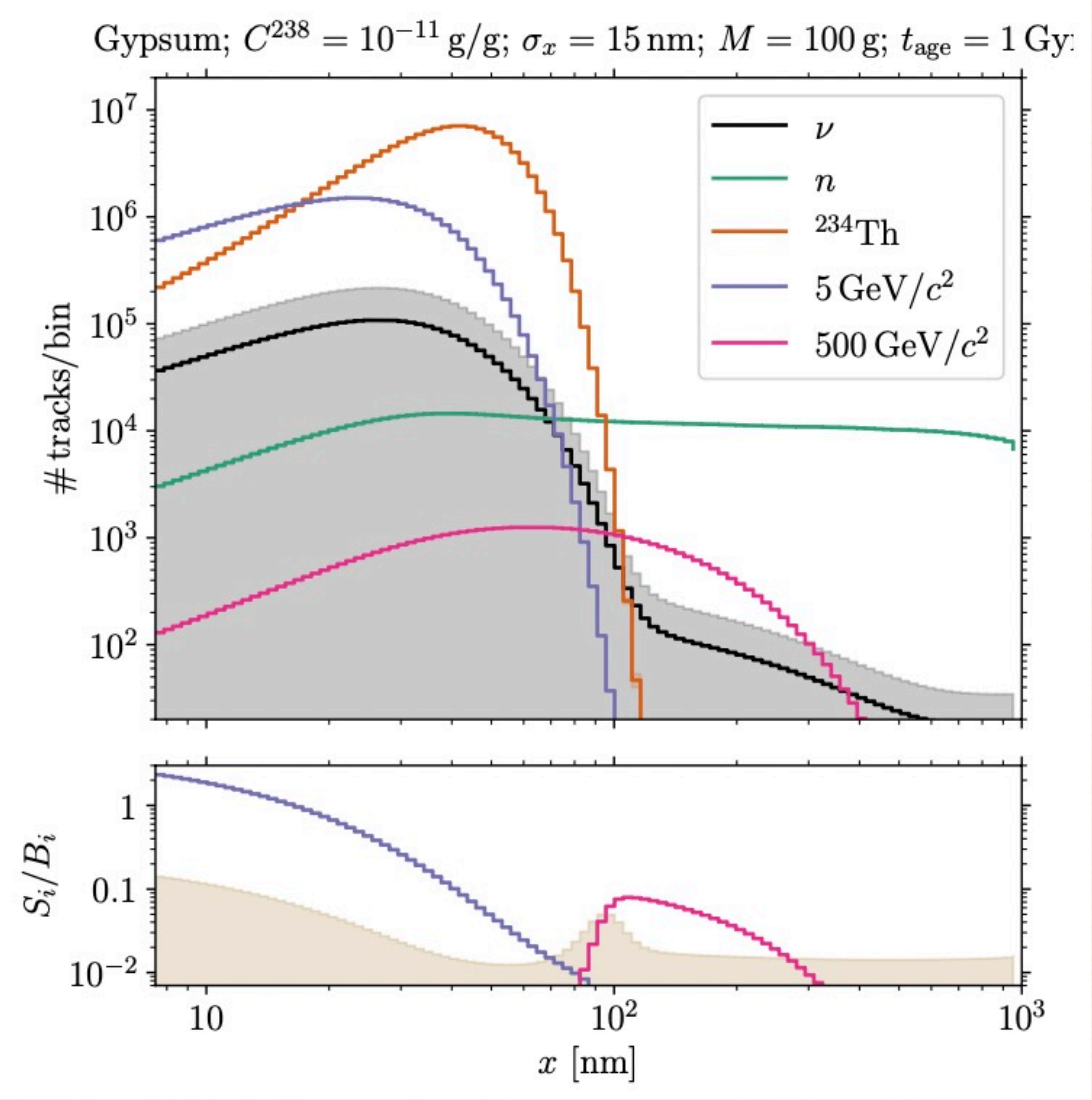
Paleo-Detectors

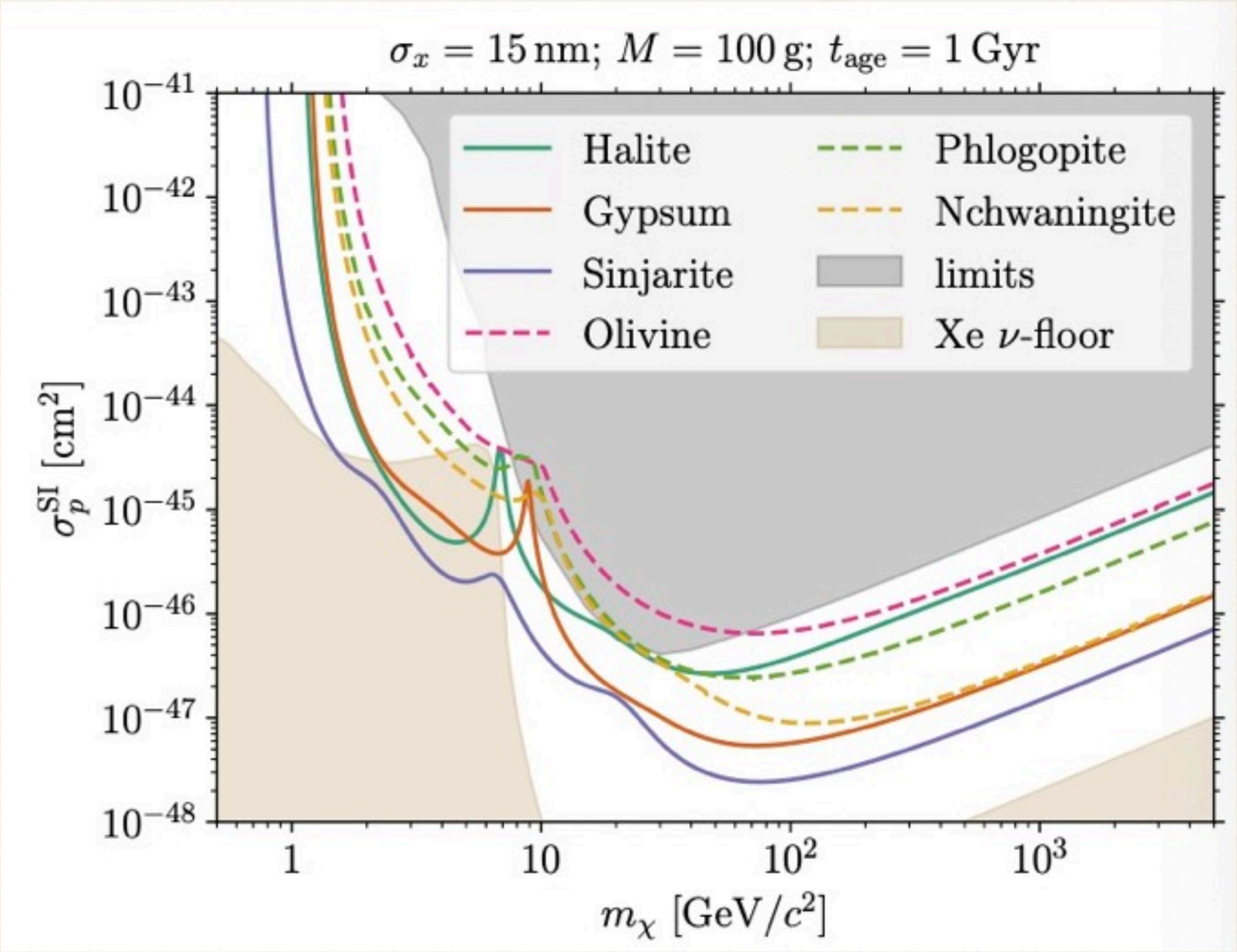
Paleo-Detectors



Marshall et al, arXiv: 2009.01028

Paleo-Detectors





Baum et al, arXiv: 2106.06559

What about subhalo contribution?

$$r_s \sim \mathcal{O}(1)pc$$

$$v_{sh} \sim \mathcal{O}(100)km/s \sim \mathcal{O}(100)pc/Myr$$

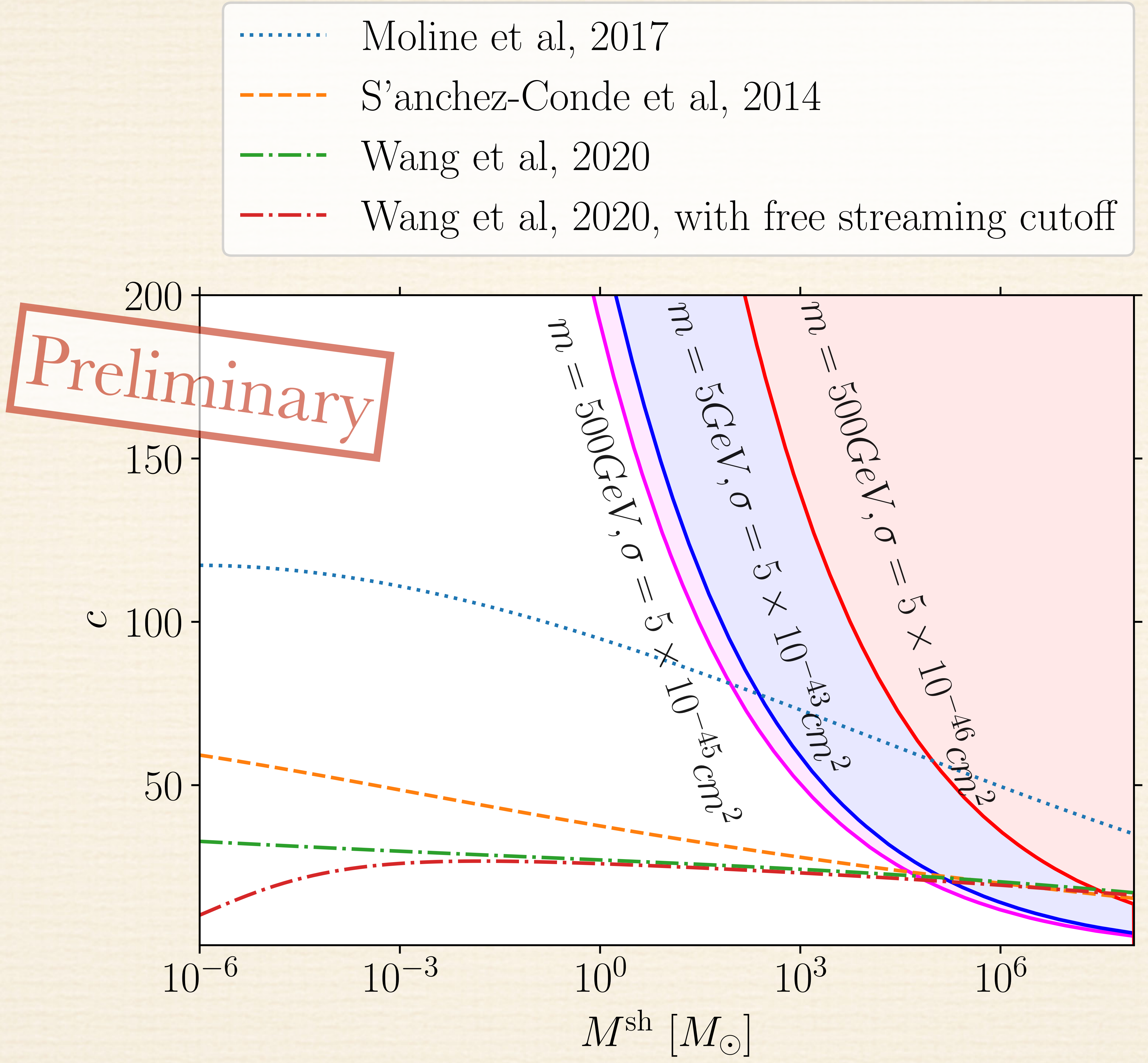
- Integration time $\sim r_S/v_{sh} \sim 10^{-2}Myrs$
- Orders of magnitudes smaller than the Milky Way integration time
- 😭😭😭

Hold on a sec!!!

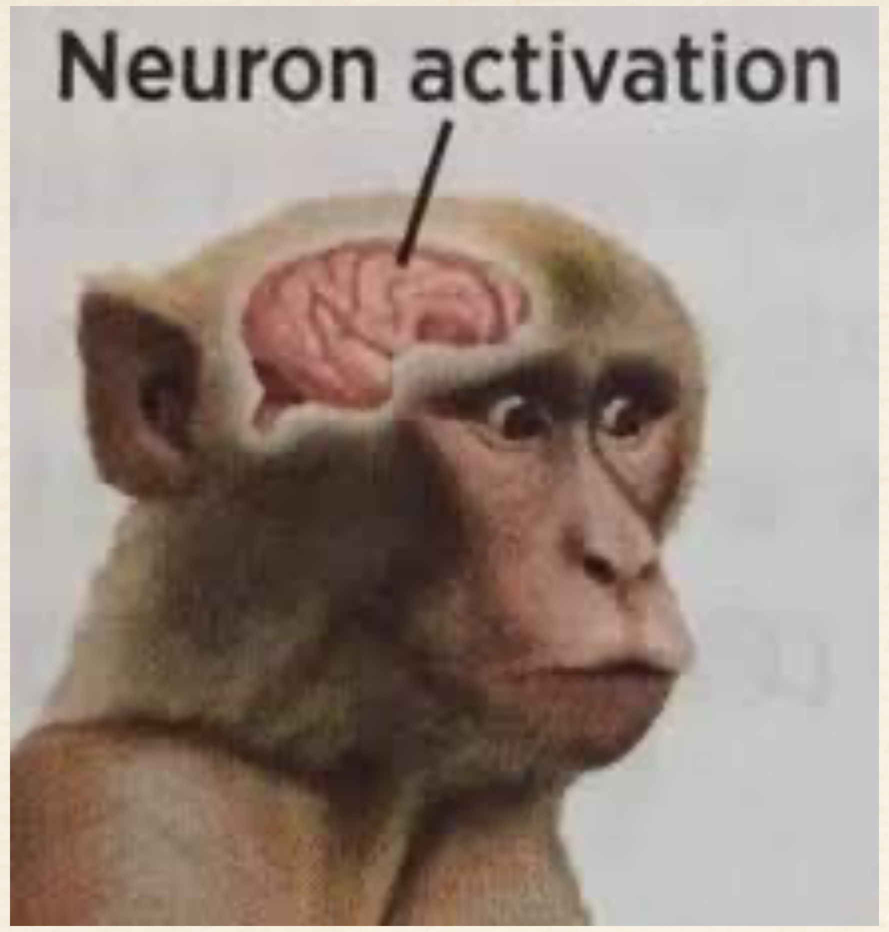
Hold on a sec!!!

Hold on a sec!!!

Time Dependent Signal



Zhang et al. (in prep).



Conclusion

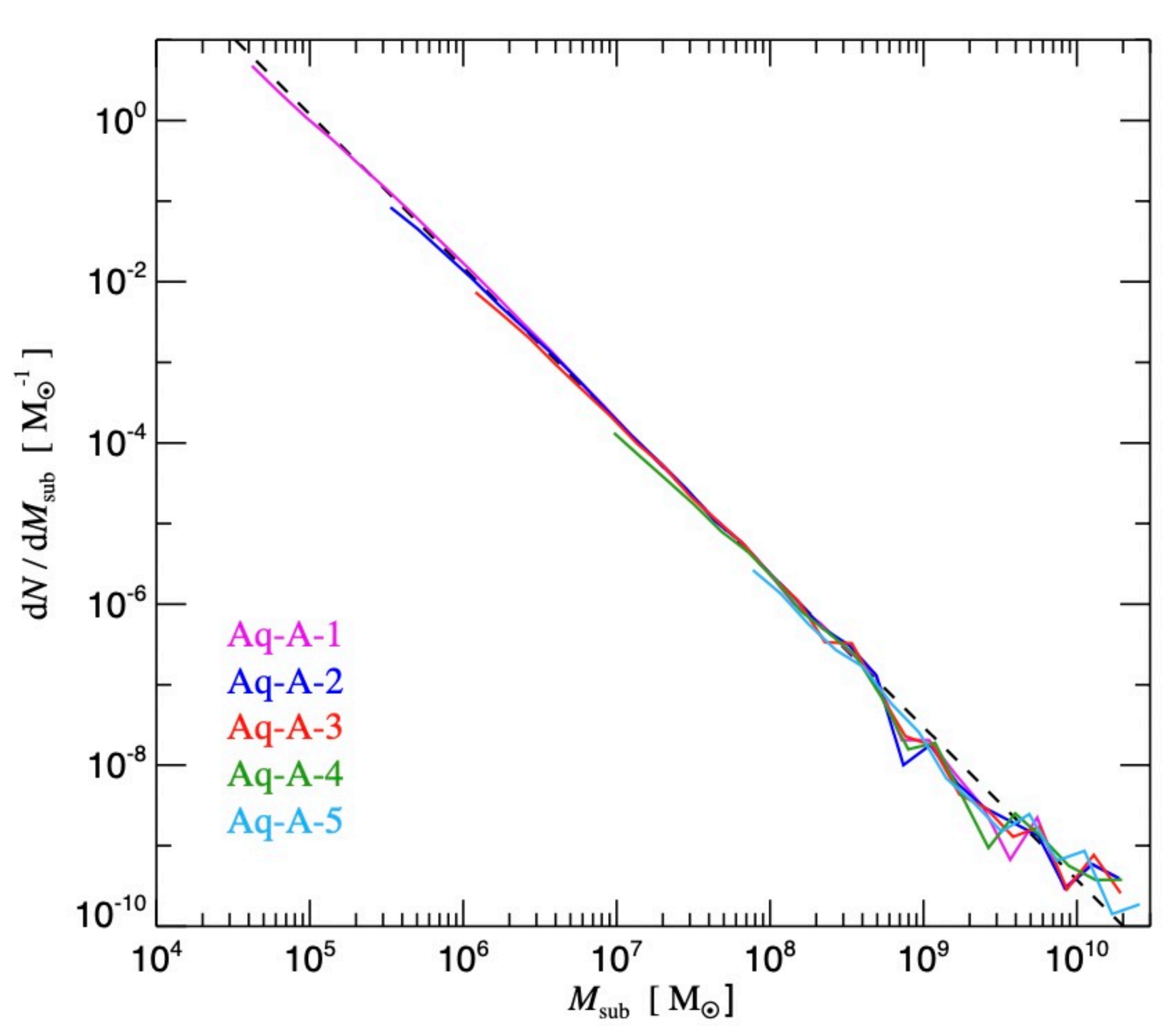
- Even though there are much more low mass subhalos out there, it is very unlikely for them to hit us. Therefore it is unlikely to have an impact on our direct detection.
- Experiments like paleo-detectors might be used to constrain the subhalo properties.

Backup Slides

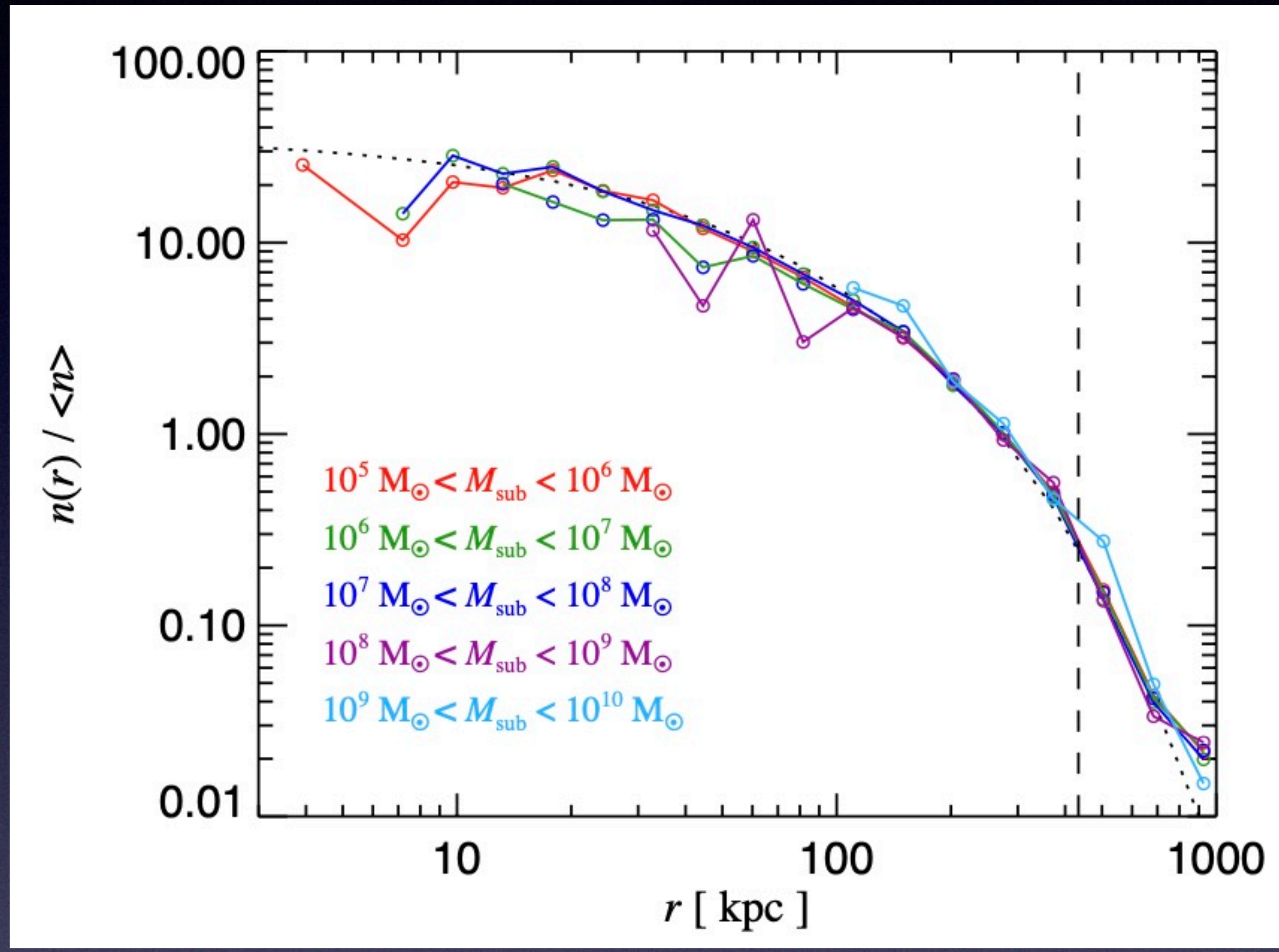
Local Differential Number Density

$$\frac{dN_{sub}}{dM_{sub}} = a_0 \left(\frac{M_{sub}}{m_0} \right)^{\beta}$$

$$n_{sub} \propto exp[-\frac{2}{\alpha}(\left(\frac{r}{r_{-2}}\right)^{\alpha} - 1)]$$



Springel, 0809.0898



Springel, 0809.0898

According to the scaling relations, we can factor them out to reach at an expression of a normalized local differential number density:

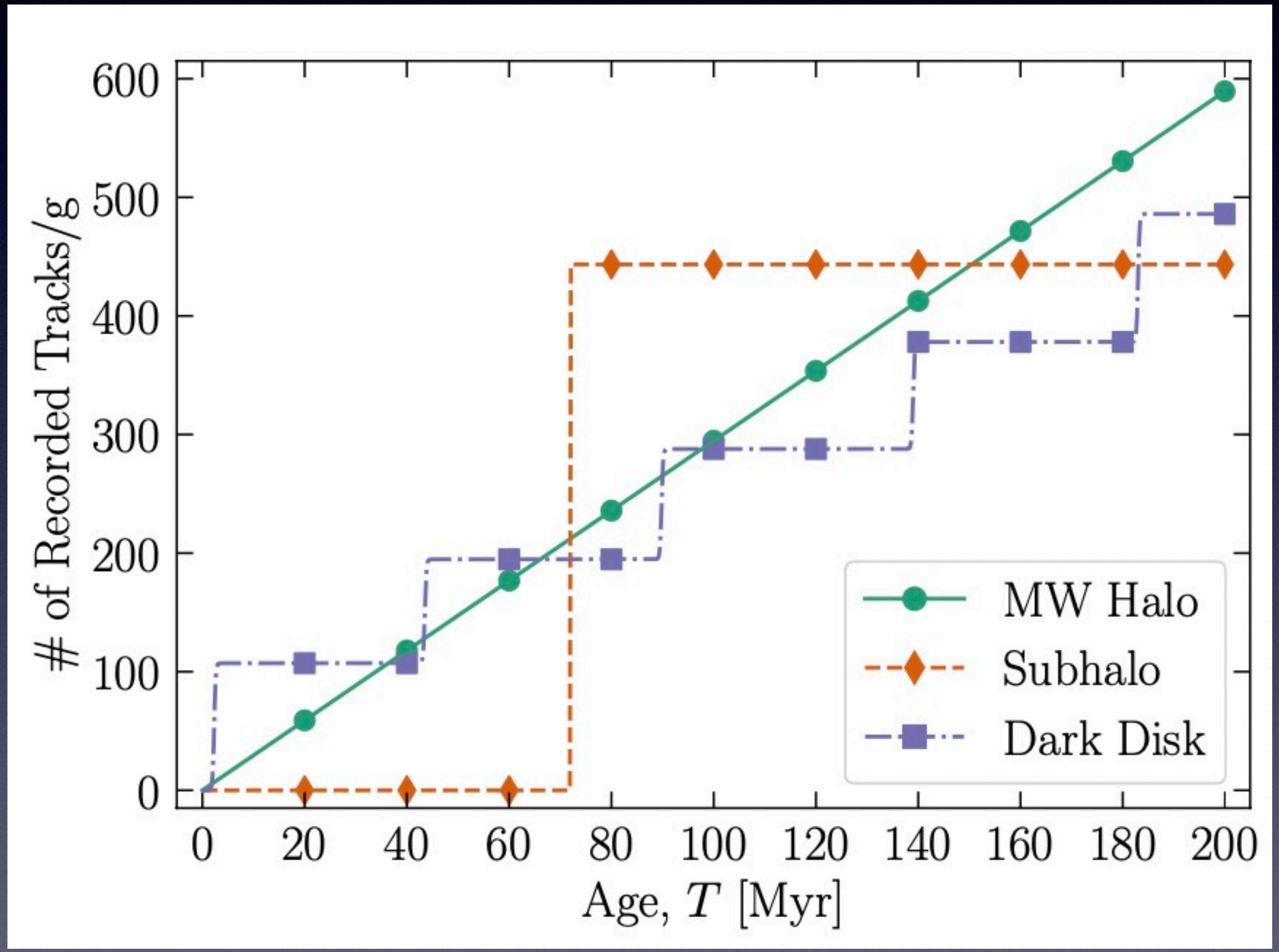
$$\frac{dn_{sub}}{dM_{sub}} = c_0 \left(\frac{M_{sub}}{m_0} \right)^{\beta} exp[-\frac{2}{\alpha}(\left(\frac{r}{r_{-2}}\right)^{\alpha} - 1)]$$

Encounter Cross-section

- Local density is measured to be around $0.3GeV/cm^3$
- A boost to the direct detection signal means the region that hits Earth of a subhalo has a density higher than the local density
- Density profile is well approximated by the Navarro-Frenk-White(NFW) profile:
- $$\rho(r) = \frac{\rho_0}{\frac{r}{R_s}(1+\frac{r}{R_s})^2},\ R_{vir} = cR_s$$
- R_{vir} and c are functions of mass only. Thus we can find b_{max} by solving $\rho(b_{max}, M) = 0.3GeV/cm^3$

Paleo Detectors

- The long exposure time of paleo-detectors also allows for a study of subhalo encountering events as a time-dependent signal if we have a series of minerals with different ages.



arXiv: 2107.02812

Paleo Detectors

- The list of parameters that affect the overall normalization of the signal includes DM particle mass m and cross section σ, subhalo mass M_{sh} and concentration parameter c, incoming velocity v and impact parameter b of the encounter.

- If we assume subhalos distribute uniformly spatially in the local area and a Maxwellian velocity distribution for the subhalos, then we can constraint the mass-concentration relation for a given dark matter particle model.