# Constraining the Self-interacting Nature of Dark Matter Using Radio Relic Clusters




**Dongak Park[1], M. James Jee[1,2], Wonki Lee[1]**

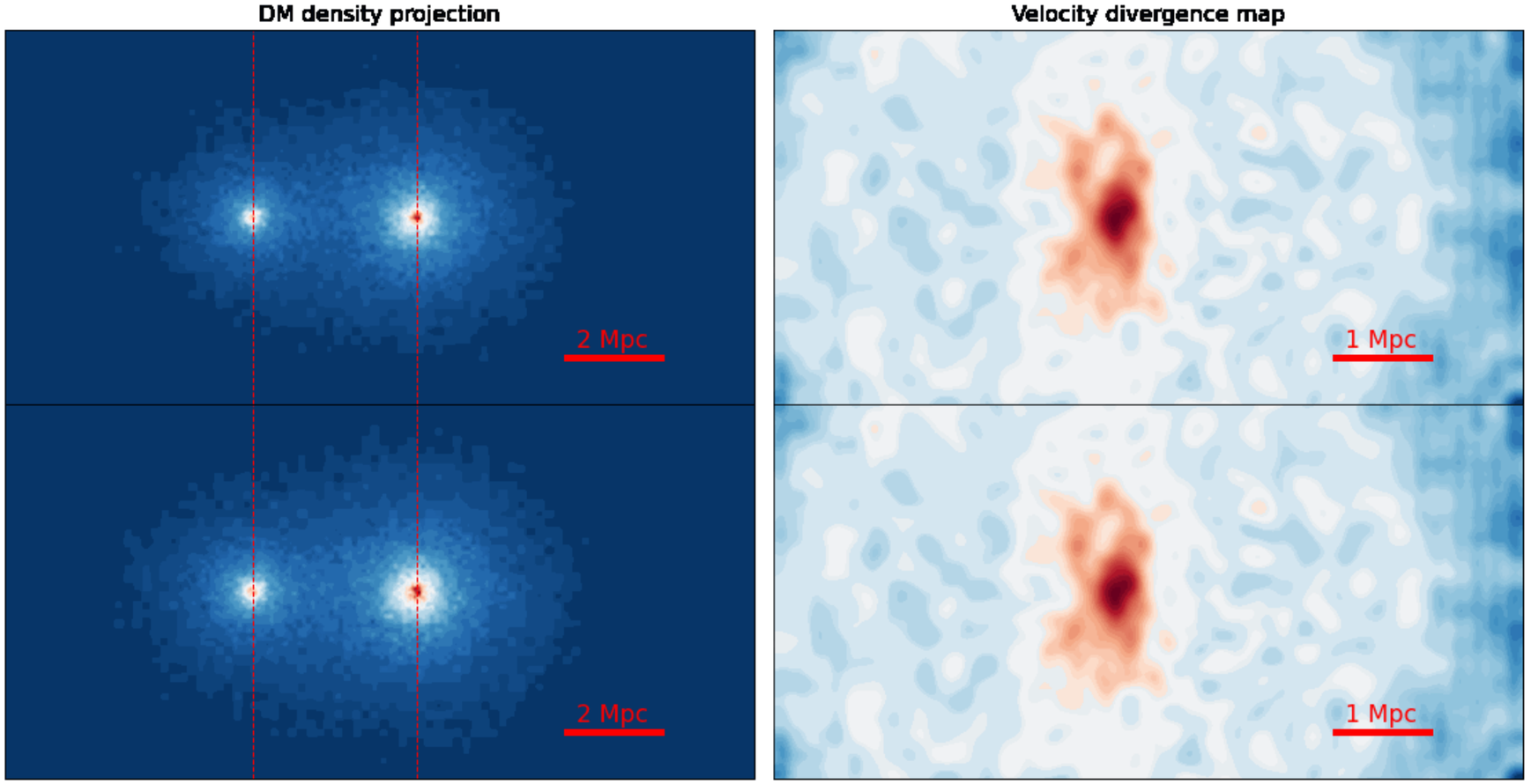
**Yonsei University[1], University of California, Davis[2]**

**The 11th KIAS Workshop on Cosmology and Structure Formation @Gyeongju**

# INTRODUCTION

CDM ($\sigma/m = 0\ \mathrm{cm}^2/\mathrm{g}$)

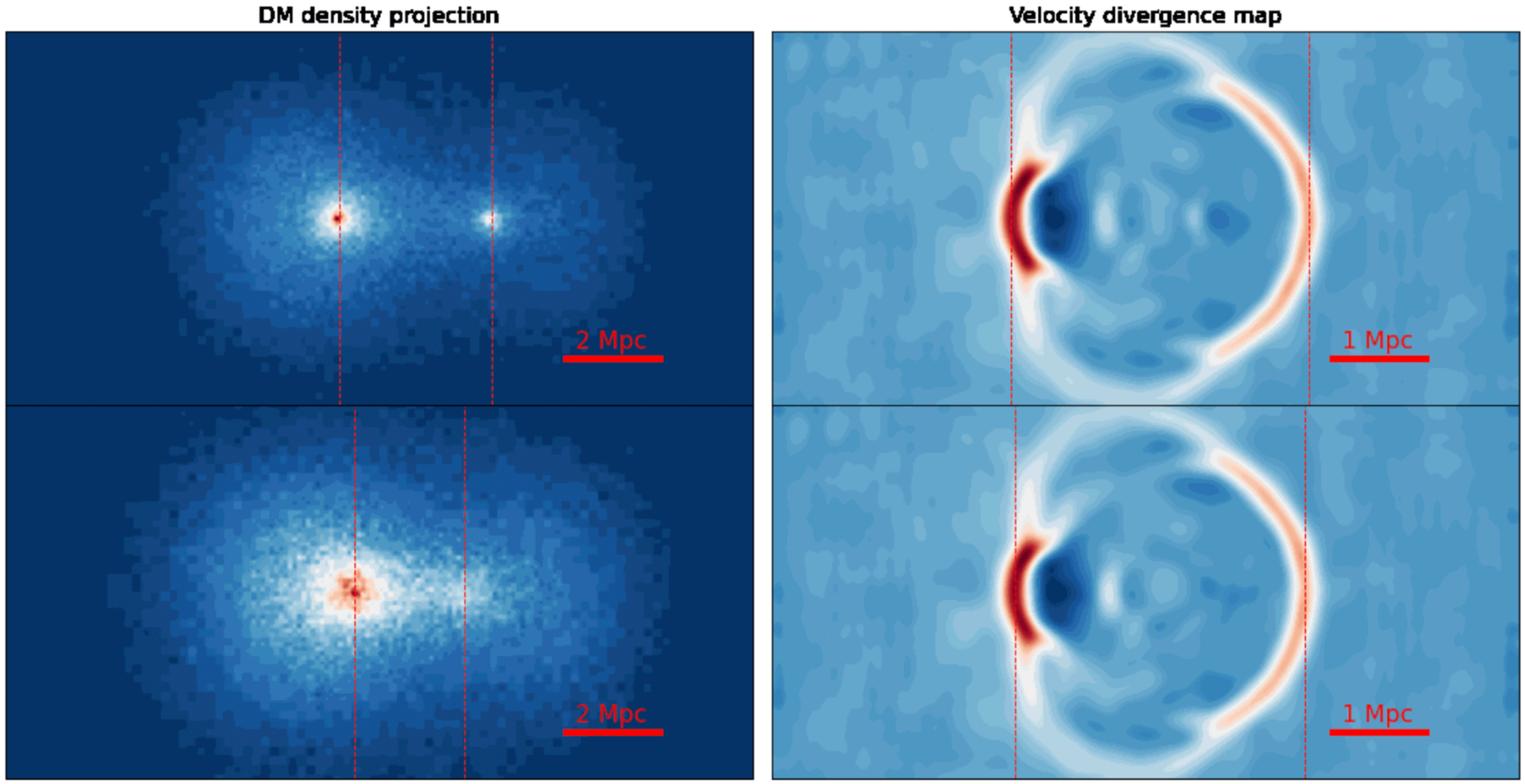
SIDM ($\sigma/m = 3\ \mathrm{cm}^2/\mathrm{g}$)



# INTRODUCTION

CDM ($\sigma/m = 0\ \mathrm{cm}^2/\mathrm{g}$)

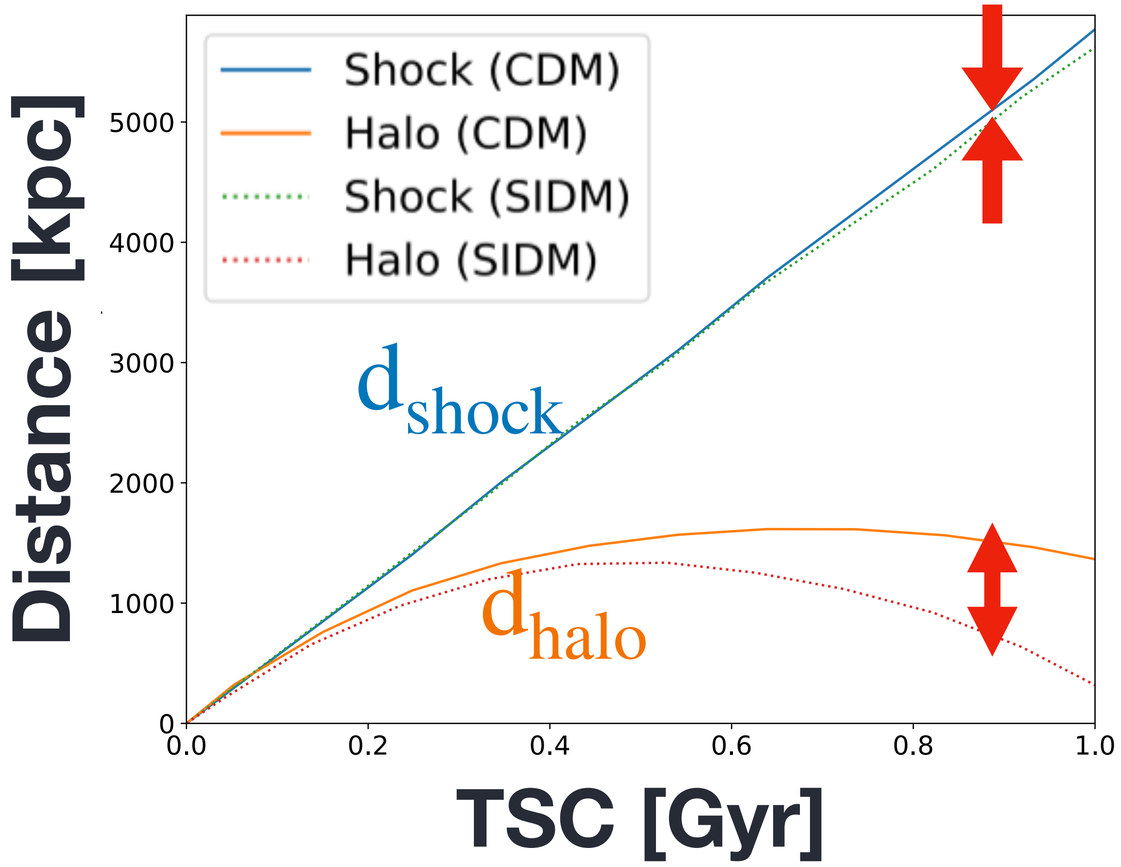
SIDM ($\sigma/m = 3\ \mathrm{cm}^2/\mathrm{g}$)

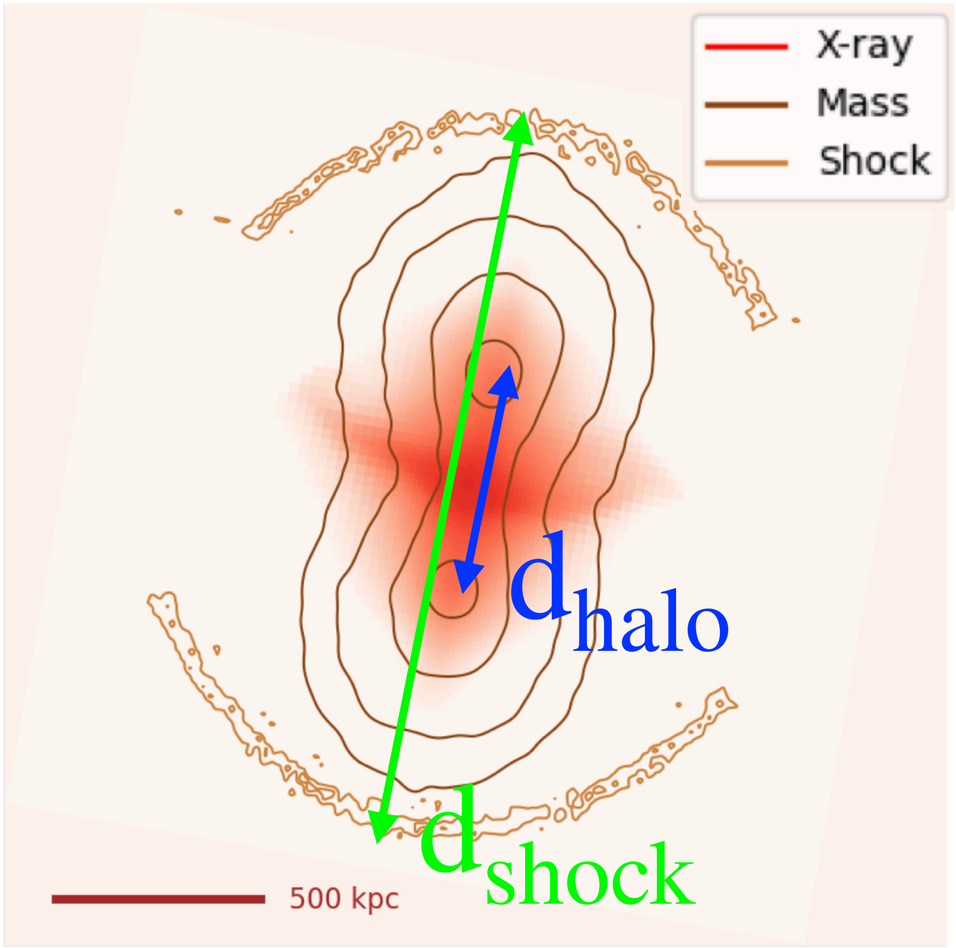


# Shock Separation ($d_{shock}$) and Halo Separation ($d_{halo}$)

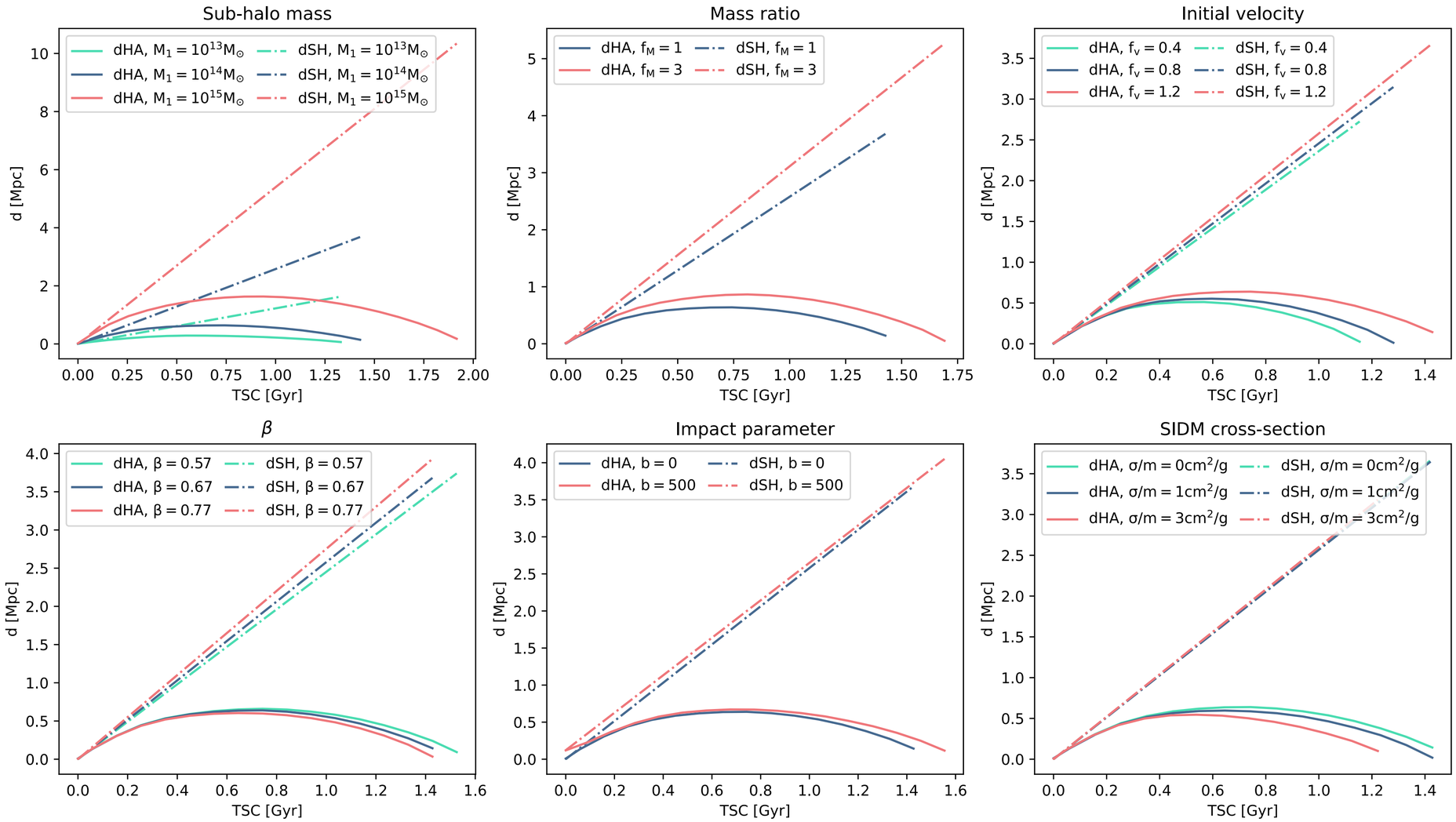
$d_{shock}$: hardly affected by $\sigma/m$(crosssection)

$d_{halo}$ : decreases as $\sigma/m$ increases



# Merger Parameters



# METHOD

Merging Cluster Simulation

**Various Merger Parameter**



Merger Parameter Table

**Mock Merging Cluster**

# Merging Cluster Simulation

- GIZMO code (Hopkins 2015)
  built-in SIDM implementation (Rocha et al. 2017)
- Idealized simulation, binary galaxy cluster merger
- Dark Matter ($m_{DM} = 4.5 \times 10^9 \mathrm{M}_\odot$) + Gas ($m_{gas} = 5 \times 10^8 \mathrm{M}_\odot$)
  DM halo: NFW profile, Gas halo: beta profile

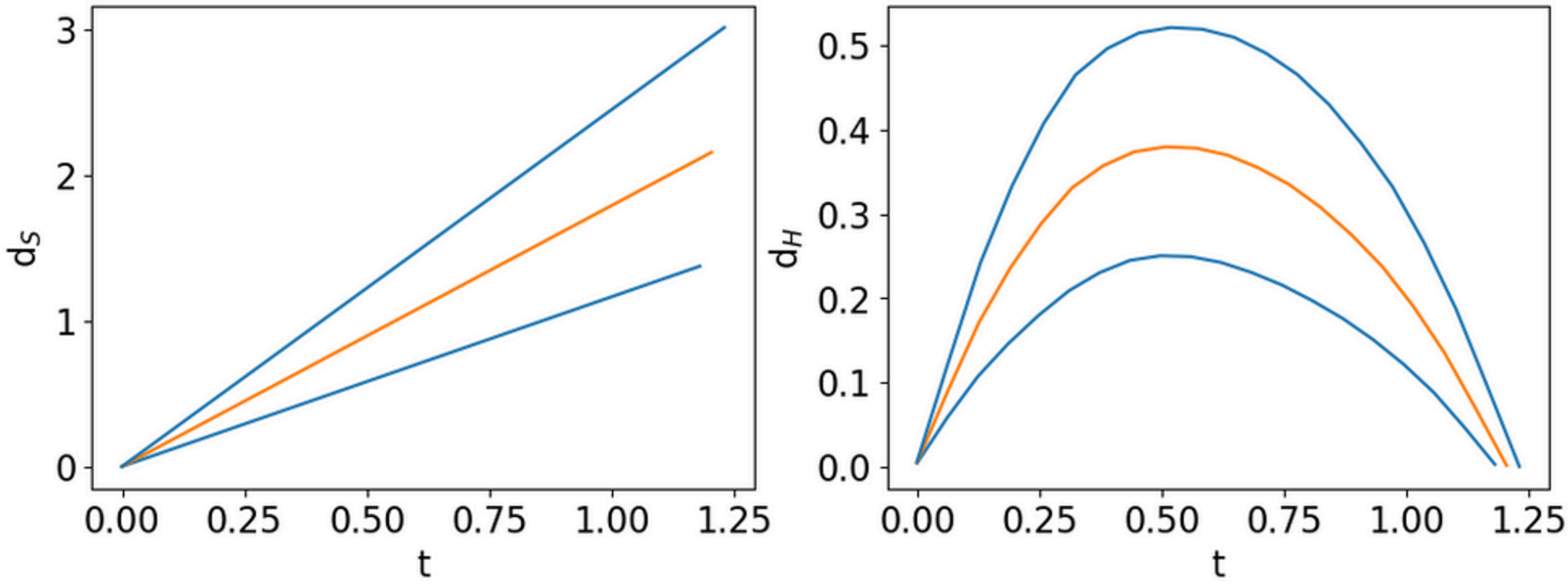
| $\mathrm{M}_1$ $[10^{14}\mathrm{M}_\odot]$ | $\mathrm{f_M}$ | $\mathrm{f_v}$ | $\beta$ | b [kpc] | $\sigma/m$ $[\mathrm{cm}^2/\mathrm{g}]$ |
|---|---|---|---|---|---|
| 0.1 | 1, 3 | 0.4, 0.8, 1.2 | 0.57, 0.67, 0.77 | 0, 250 | 0, 0.5, 1, 3 |
| 1 | 1, 3 | 0.4, 0.8, 1.2 | 0.57, 0.67, 0.77 | 0, 500 | 0, 0.5, 1, 3 |
| 5 | 1, 3 | 0.4, 0.8, 1.2 | 0.57, 0.67, 0.77 | 0, 812 | 0, 0.5, 1, 3 |
| 10 | 1, 3 | 0.4, 0.8, 1.2 | 0.57, 0.67, 0.77 | 0, 1000 | 0, 0.5, 1, 3 |

Initial condition parameters (576 simulations in total)

# Interpolation

— : Simulated

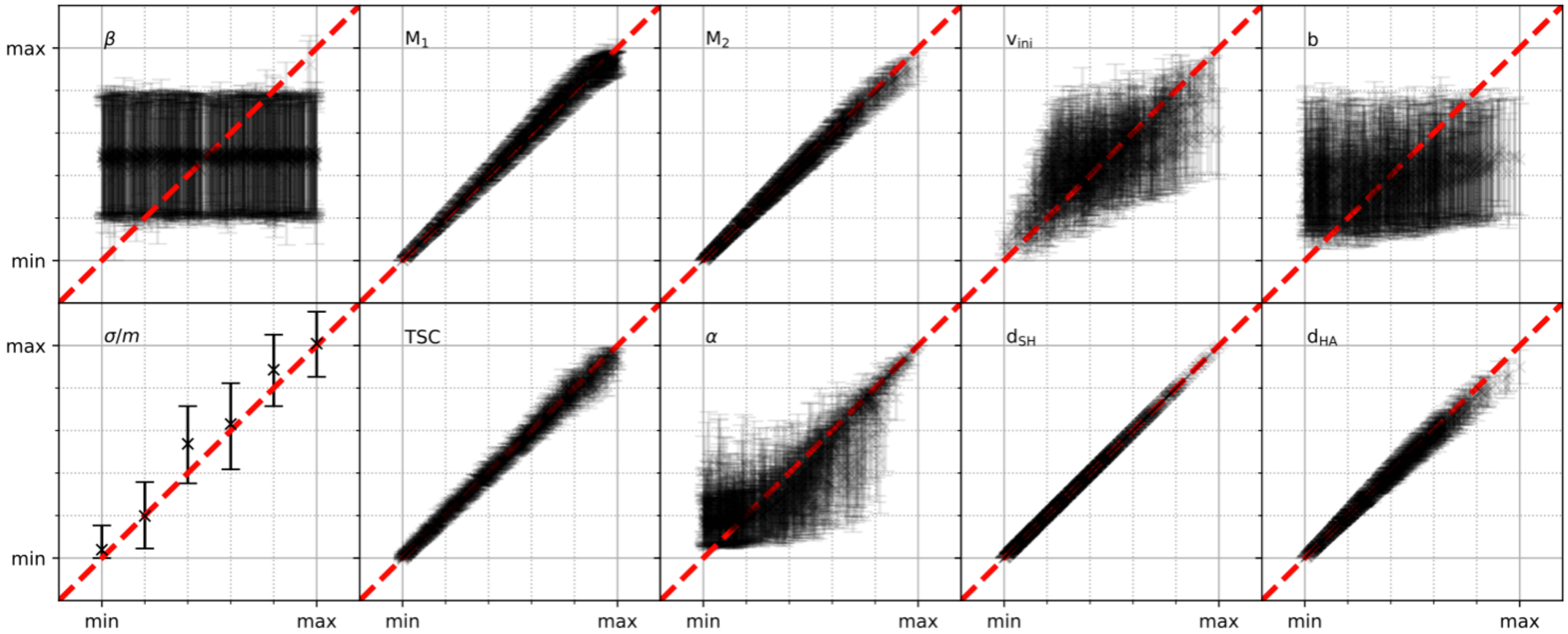
— : Interpolated



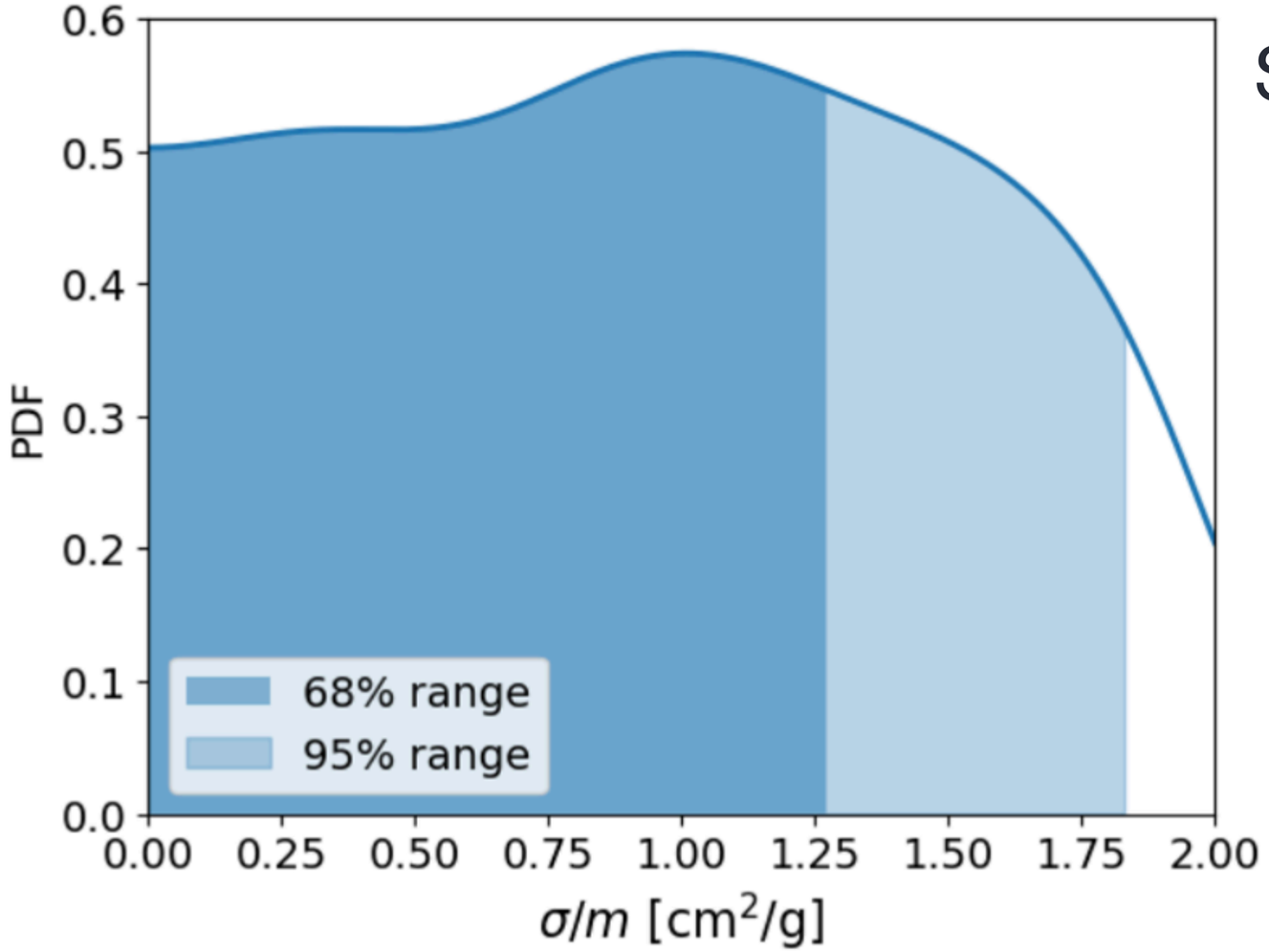
# Sanity Check

- Parameter random sampling → mock data set

$\beta$, $b$: nuisance parameter



# Example: ACT-CL J0102-4915

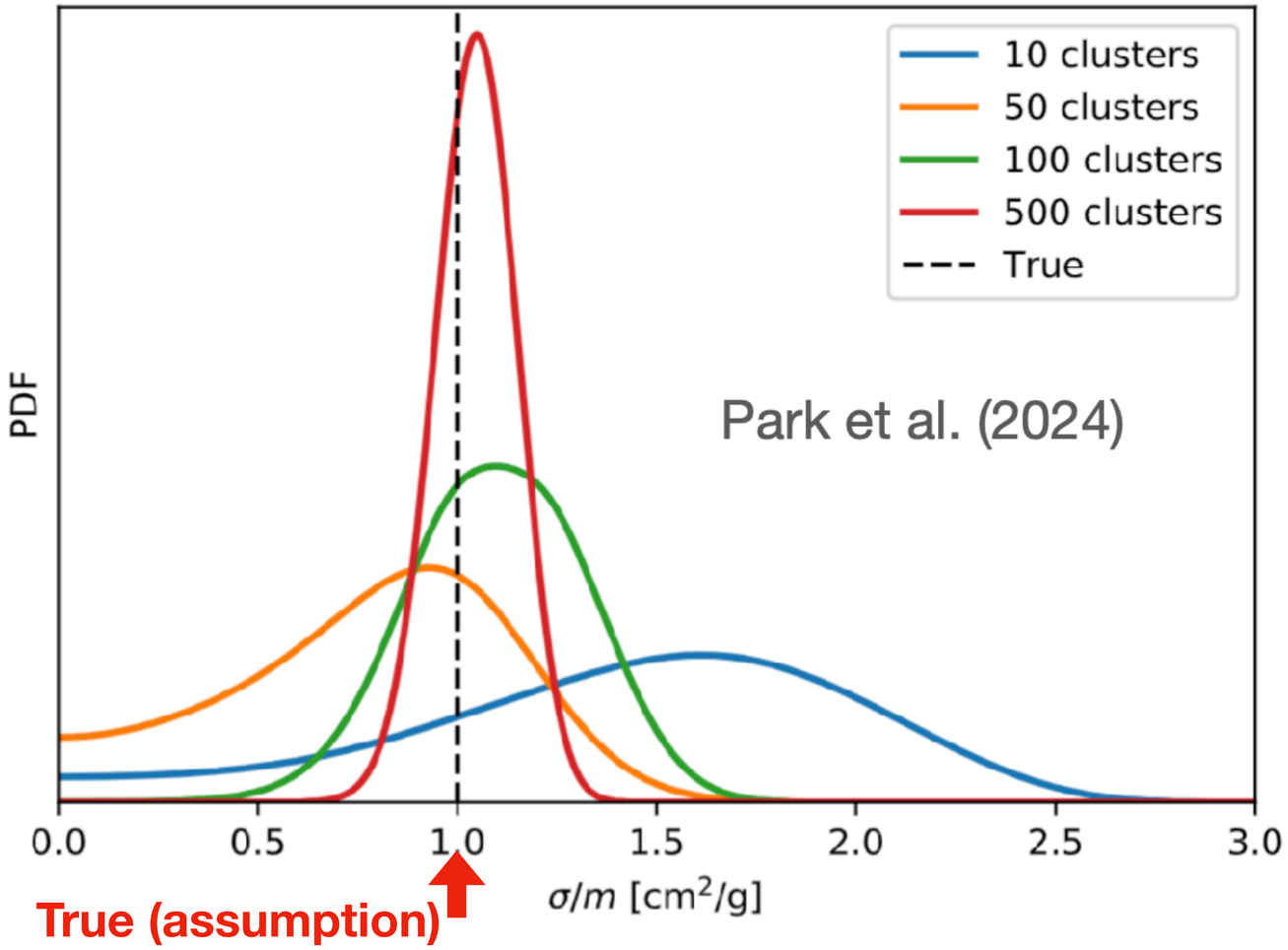



SIDM cross-section

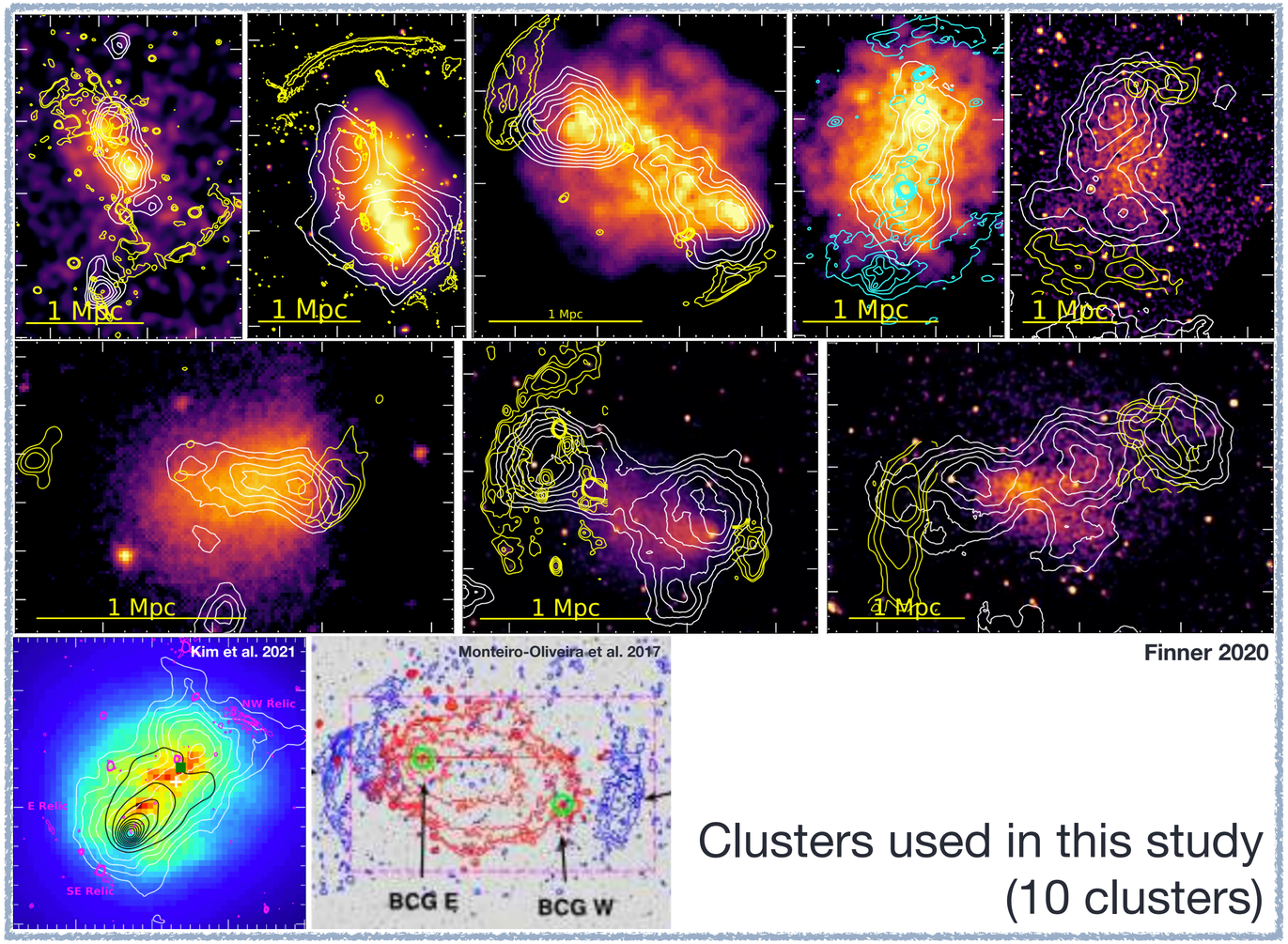
# Joint Probability Density Function

$$\mathrm{PDF}_{\mathrm{joint}}(\sigma/\mathrm{m}) = \mathrm{P}_1(\sigma/\mathrm{m}) \times \mathrm{P}_2(\sigma/\mathrm{m}) \times \cdots$$

**Test with mock Data**



# Merging Cluster Samples



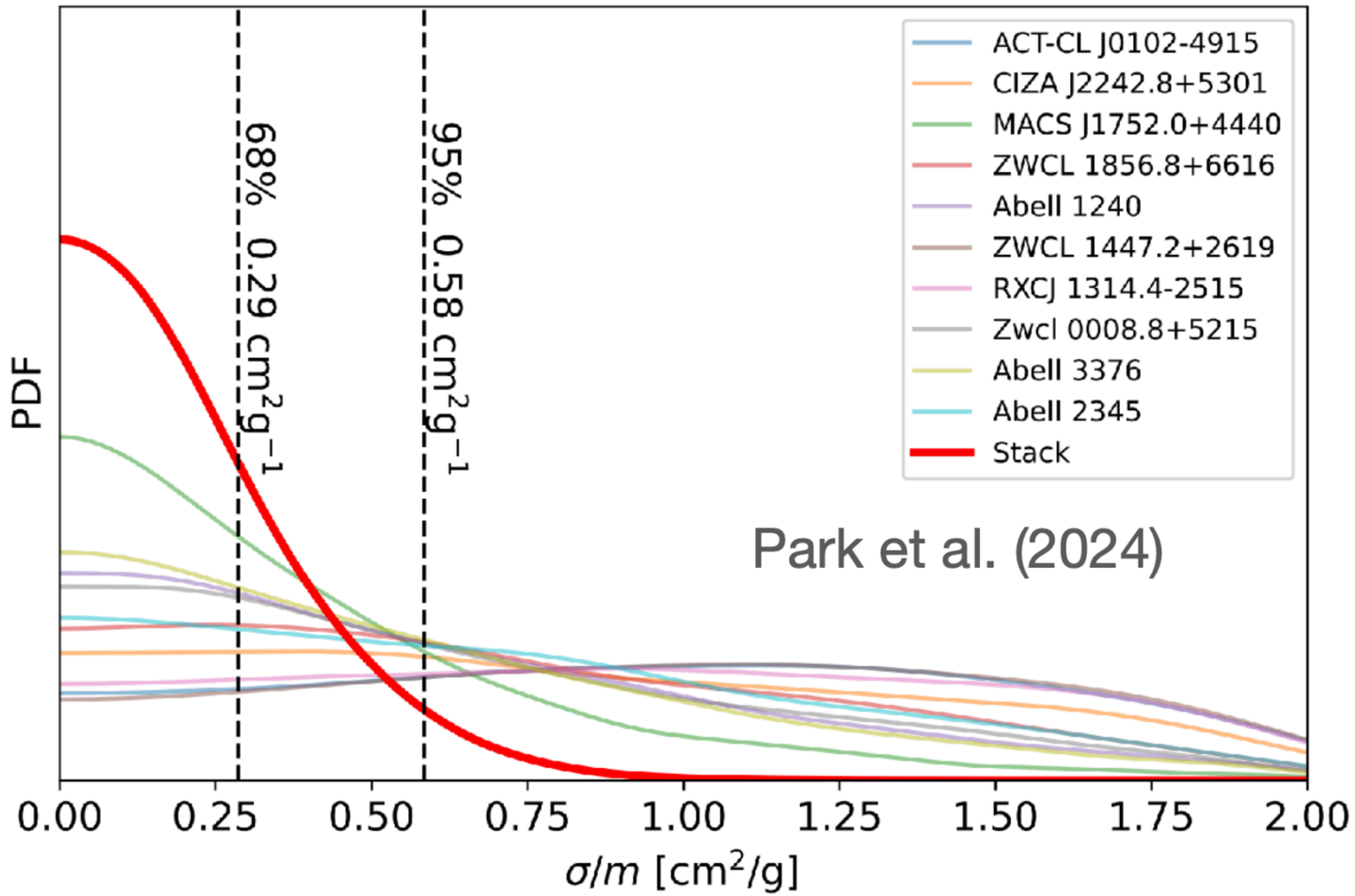

Clusters used in this study
(10 clusters)

## Merging Cluster Sample Selection

- Binary mass peak
- Symmetric binary radio relic (close to head-on merger)
- Mass estimation (weak gravitational lensing)

# SIDM Cross-section Constraint

## Real Cluster Data



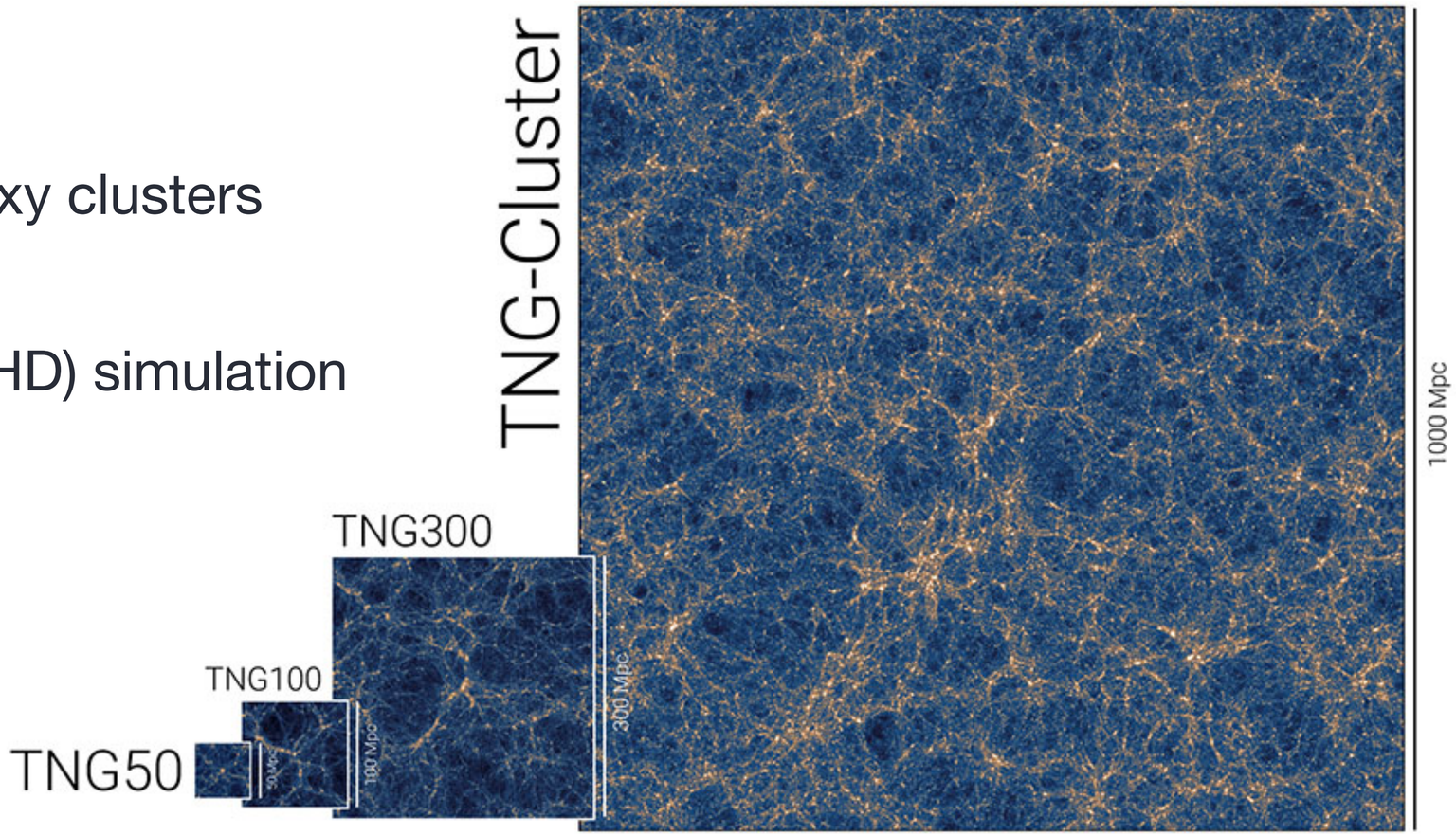

**Galaxy-mass offset**
**(without radio relic information)**
Randall et al. 2008
: $\sigma/m \leq 1.25\ \mathrm{cm}^2/\mathrm{g}$ (68%)
Wittman et al. 2018
: $\sigma/m \leq 2\ \mathrm{cm}^2/\mathrm{g}$ (95%)

**Using radio relic (This work)**
$\sigma/m \leq 0.32\ \mathrm{cm}^2/\mathrm{g}$ (68%)
$\sigma/m \leq 0.79\ \mathrm{cm}^2/\mathrm{g}$ (95%)

# Cosmological Context

## TNG-Cluster

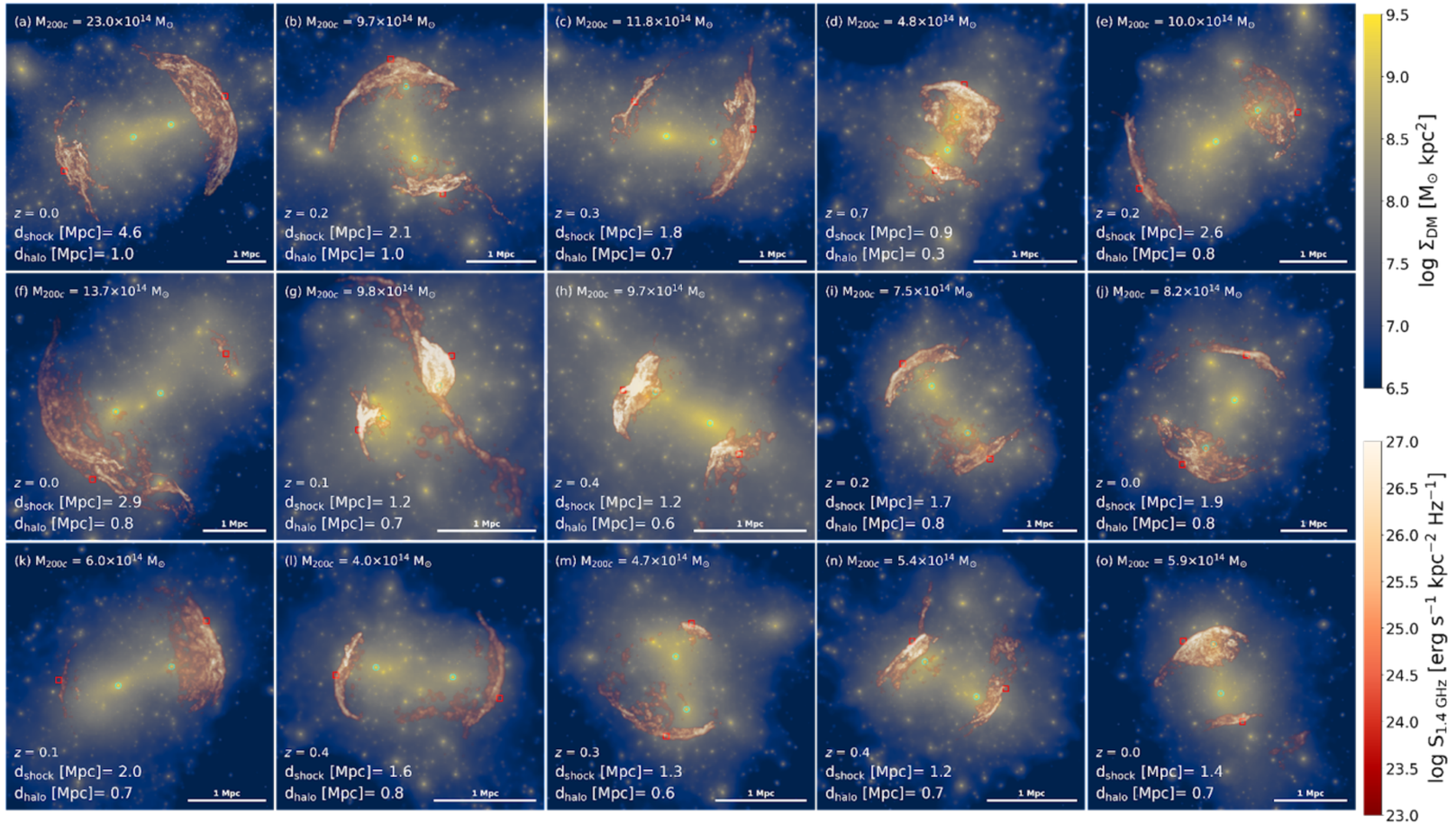
- Extension of TNG-300
- Zoom-in simulation of galaxy clusters (~350 clusters)
- MagnetoHydroDynamic(MHD) simulation
- AGN & stellar feedback



# Cosmological Context

## TNG-Cluster data

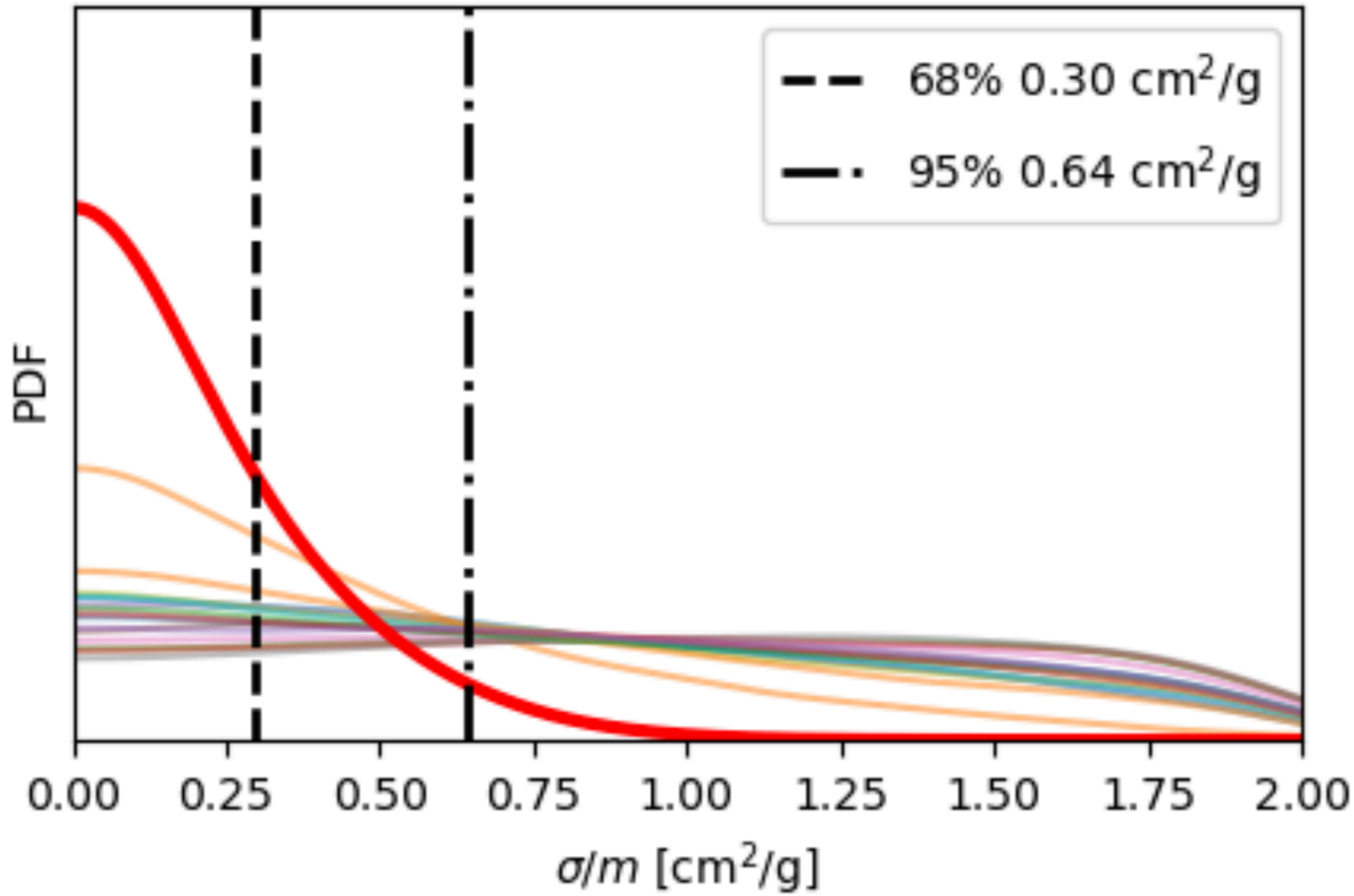
- Massive clusters
  $M \gtrsim 10^{14} M_{\odot}$
- Small mass ratio
  (major merger)
  $f_M \lesssim 3$
- Clear binary & symmetric radio relics



# Cosmological Context

## TNG-Cluster data

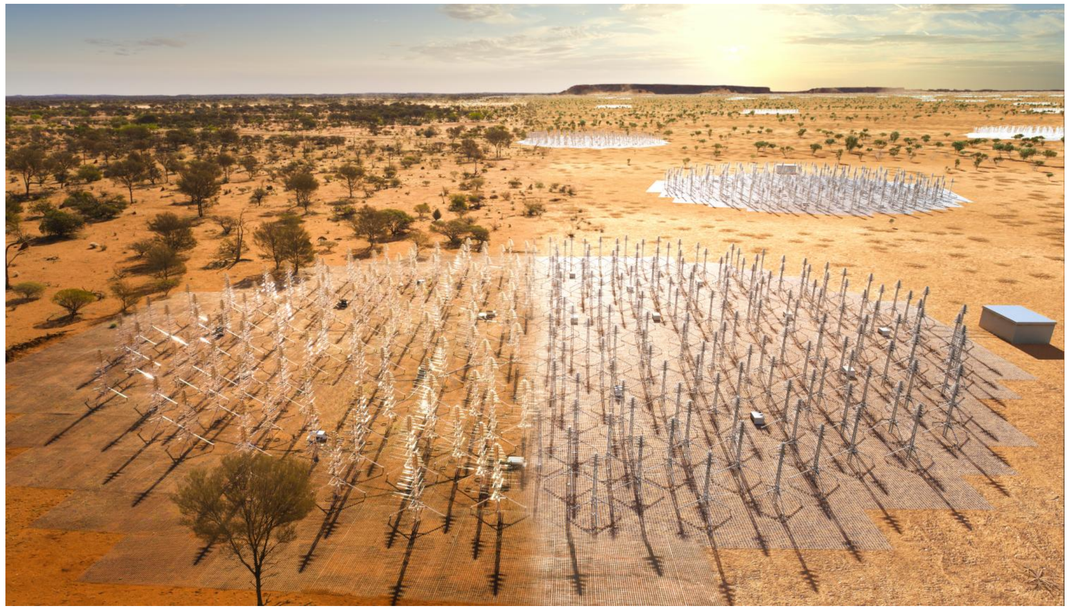
**Similar results with the real cluster samples!**




$$(\sigma/m)_{true} = 0$$

# Square Kilometer Array (SKA)

- More radio relic clusters tighten the prediction
- SKA might be able to find up to ~5000 radio relics (Ascaso et al. 2015)



SKA-LOW

# Summary

- We found that radio relics is helpful to understand the self-interacting nature of dark matter
- Based on our simulation, we constructed **a new method to constrain** $\sigma/m$
- We applied our method to 10 real merging galaxy cluster samples, and obtained **tight constraint on** $\sigma/m$
- We expect the upcoming **Square Kilometre Array (SKA)** will provide much **more ( ~ 5000) merging galaxy cluster** samples with relics