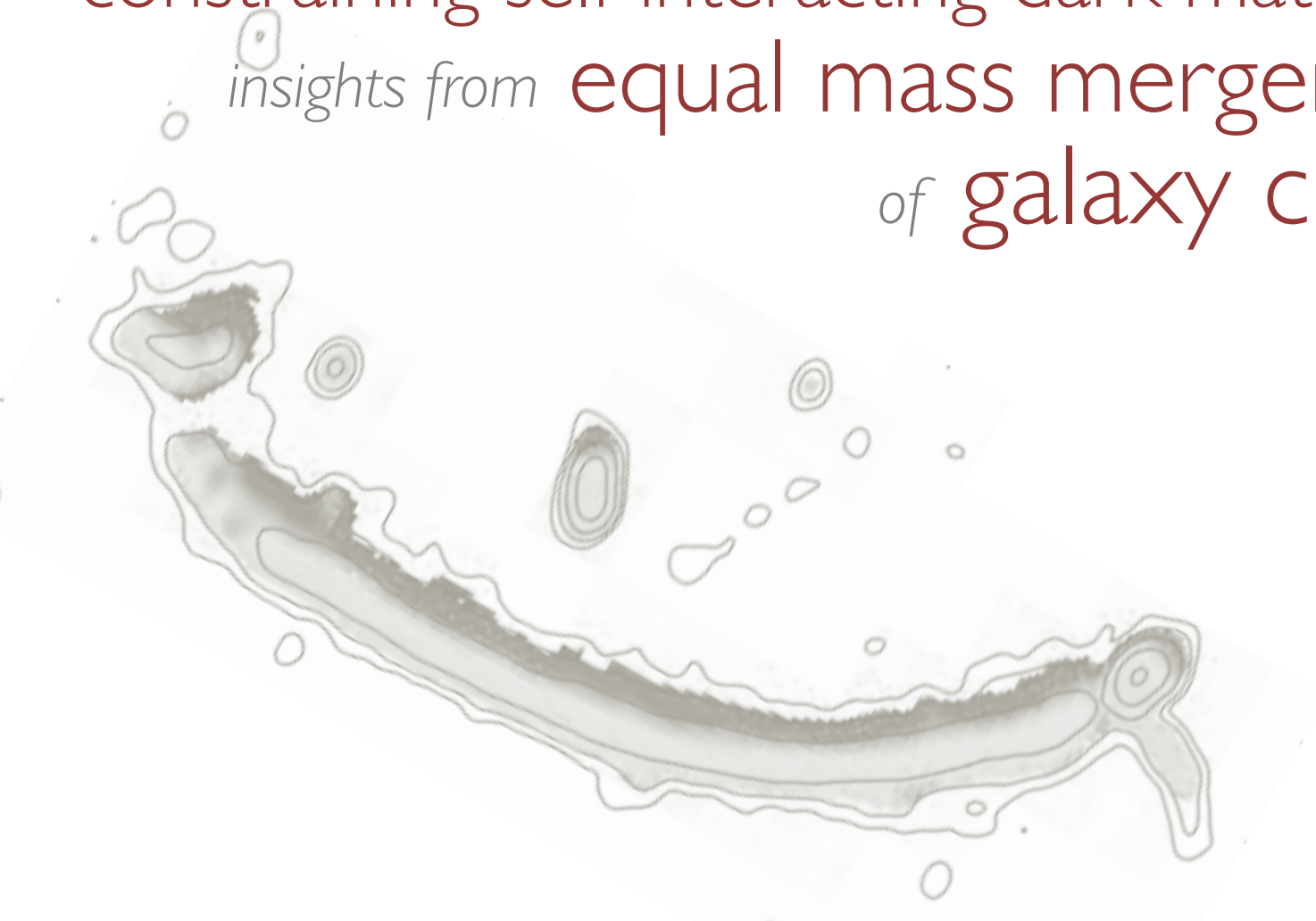
TeVPA 2017

constraining self-interacting dark matter: *insights from* equal mass mergers *of* galaxy clusters



S. Y. Kim

A. H. G. Peter

D. Wittman

CDM a success!

CDM typically assumed to be collisionless, i.e. $\frac{\sigma}{m_\chi} = 0$.

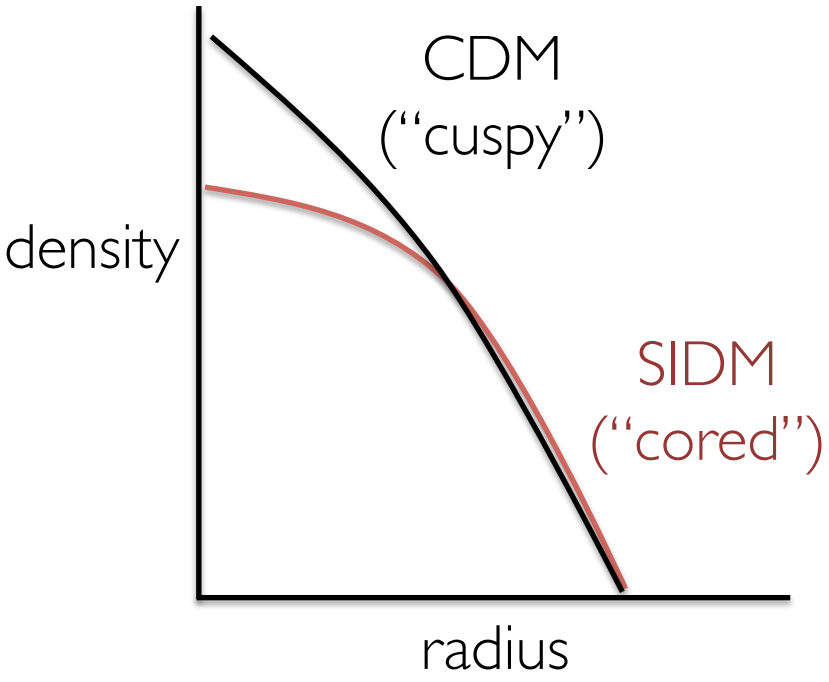
How good is this assumption?

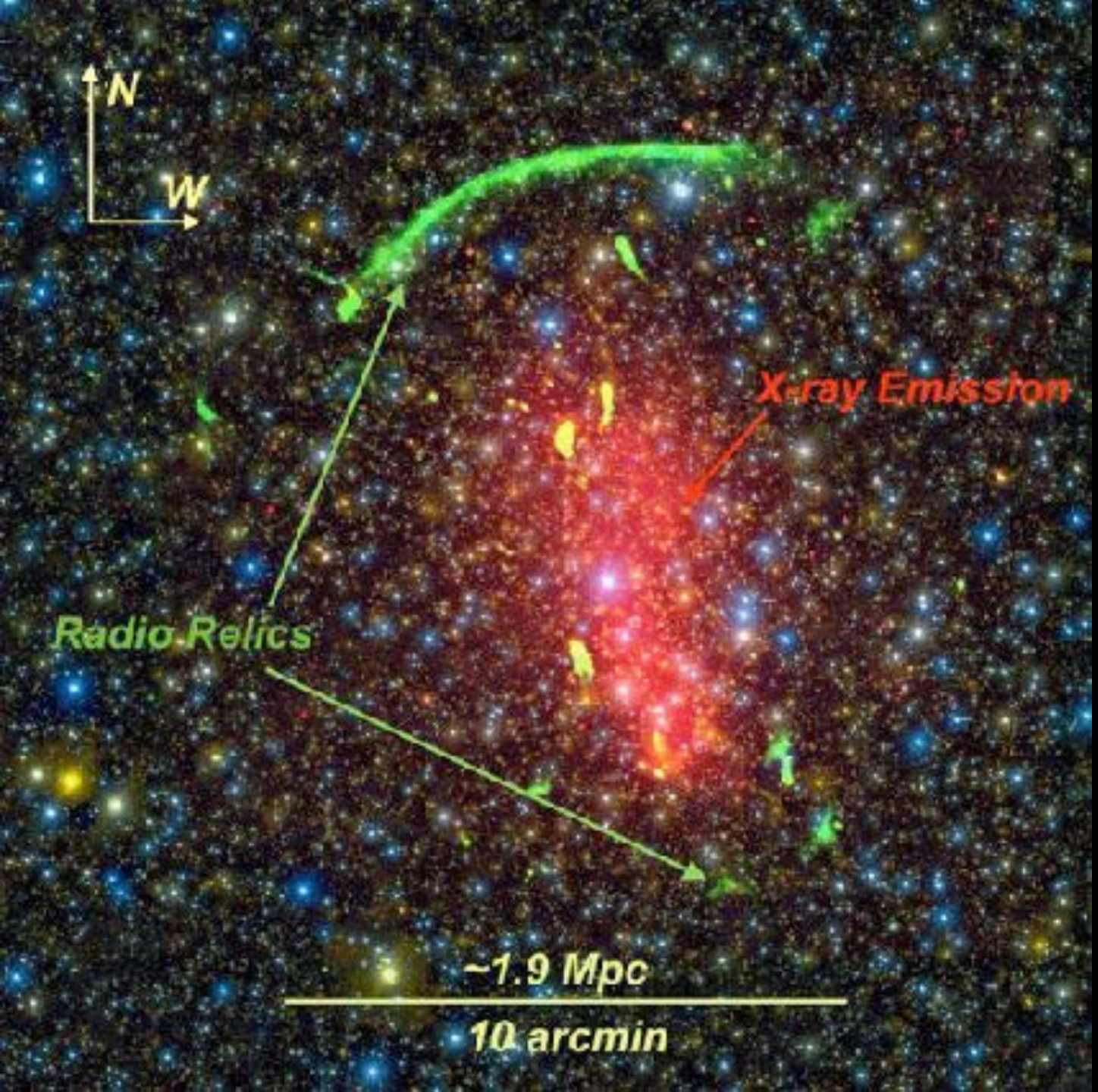
CDM a success!

CDM typically assumed to be collisionless, i.e. $\frac{\sigma}{m_\chi} = 0$.

How good is this assumption?

If $\frac{\sigma}{m_\chi} \neq 0$, collisional or "self-interacting."

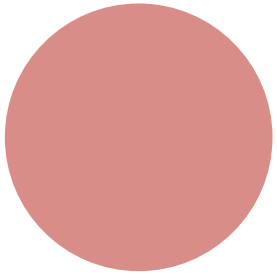




The Sausage Cluster

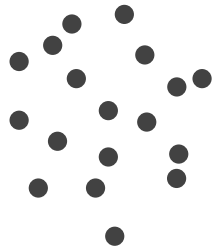
Jee+ 2015

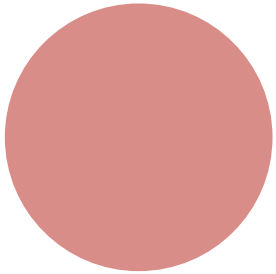
a galaxy cluster contains



dark matter

a galaxy cluster contains

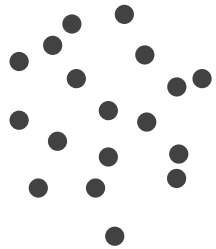




collisionless
galaxies

dark matter

a galaxy cluster contains



collisionless
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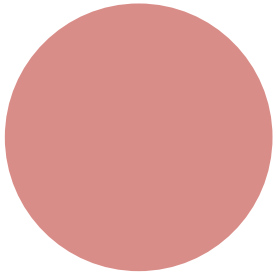
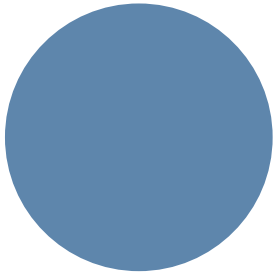


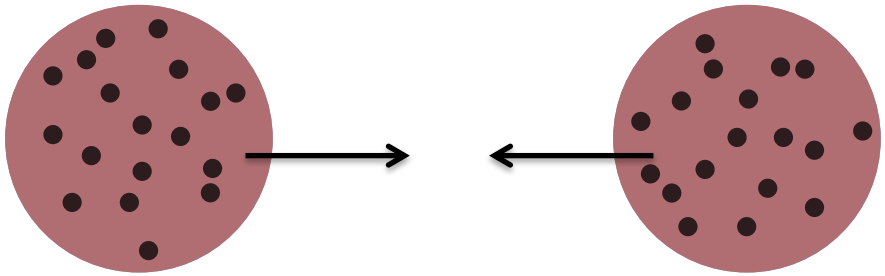
dark matter



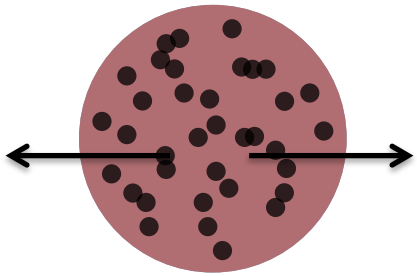
highly
collisional
gas

a galaxy cluster merger

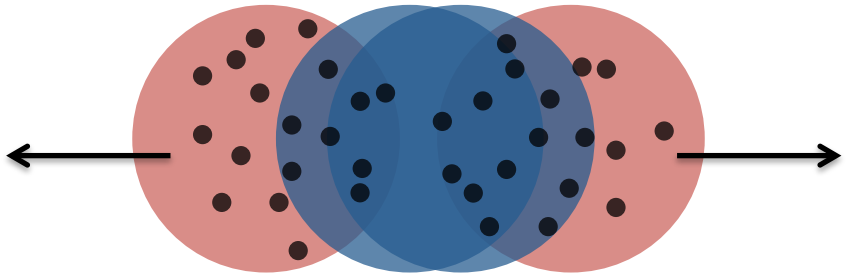
a galaxy cluster merger



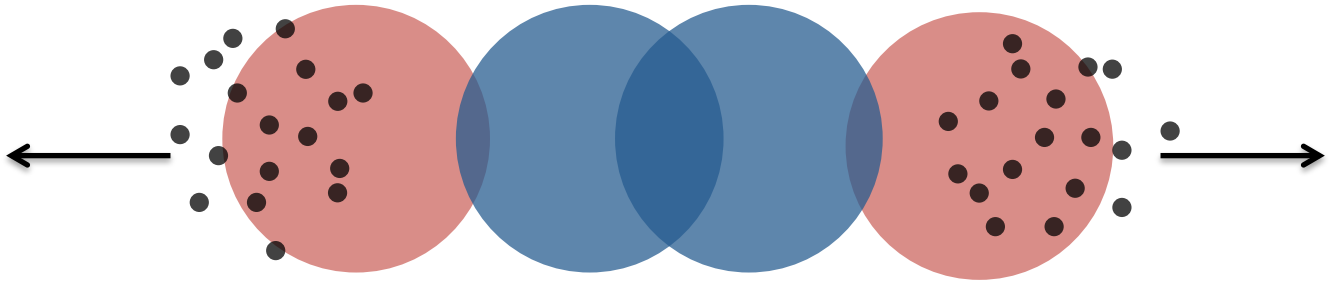
a galaxy cluster merger

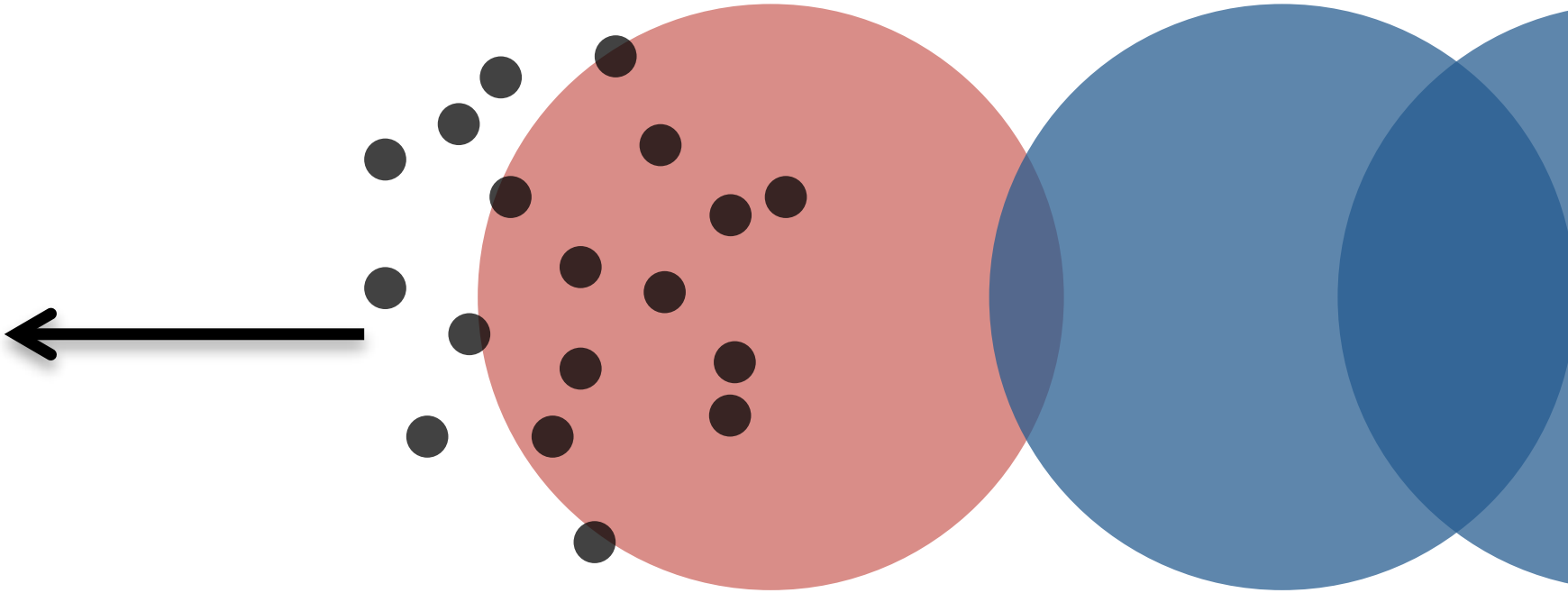


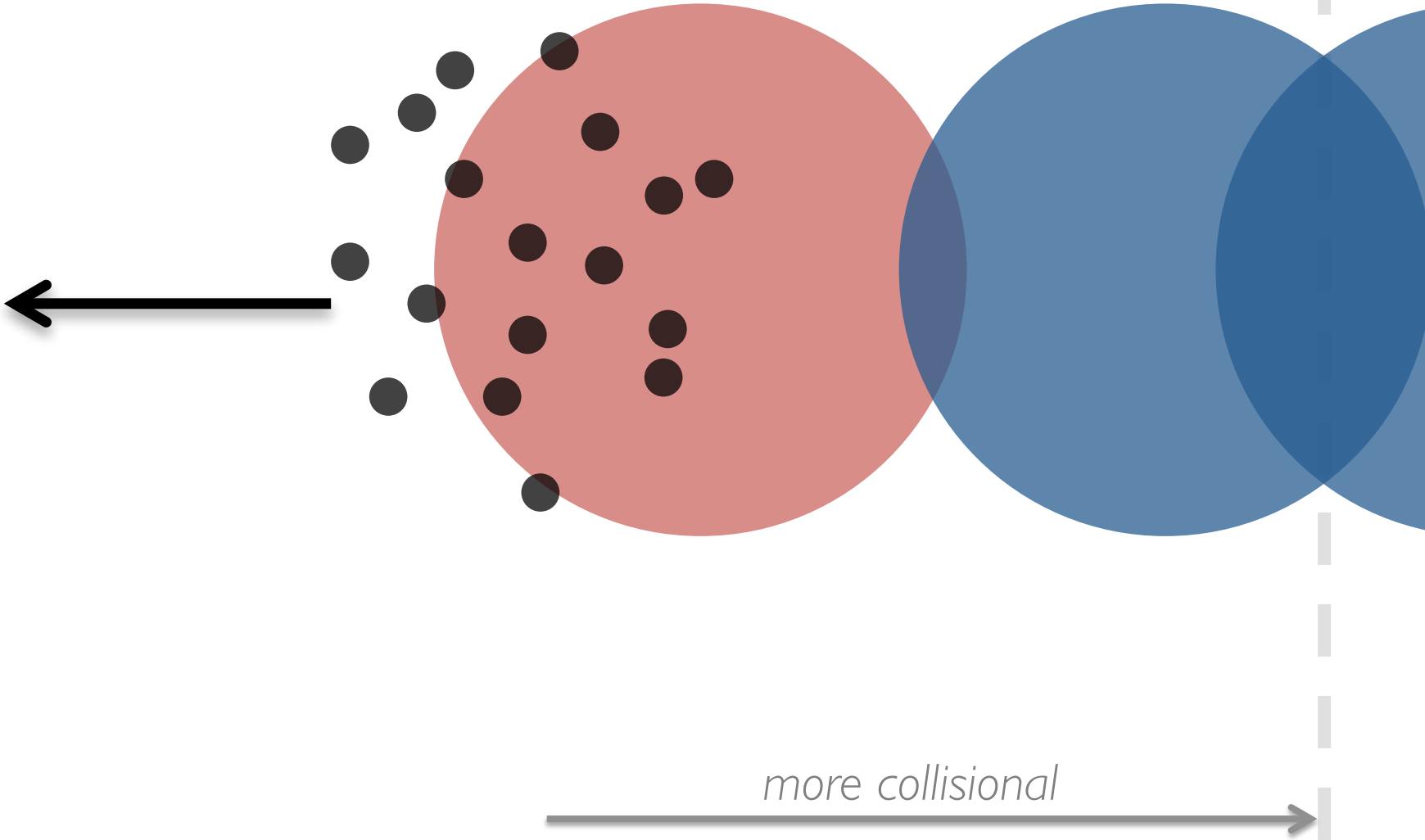
a galaxy cluster merger

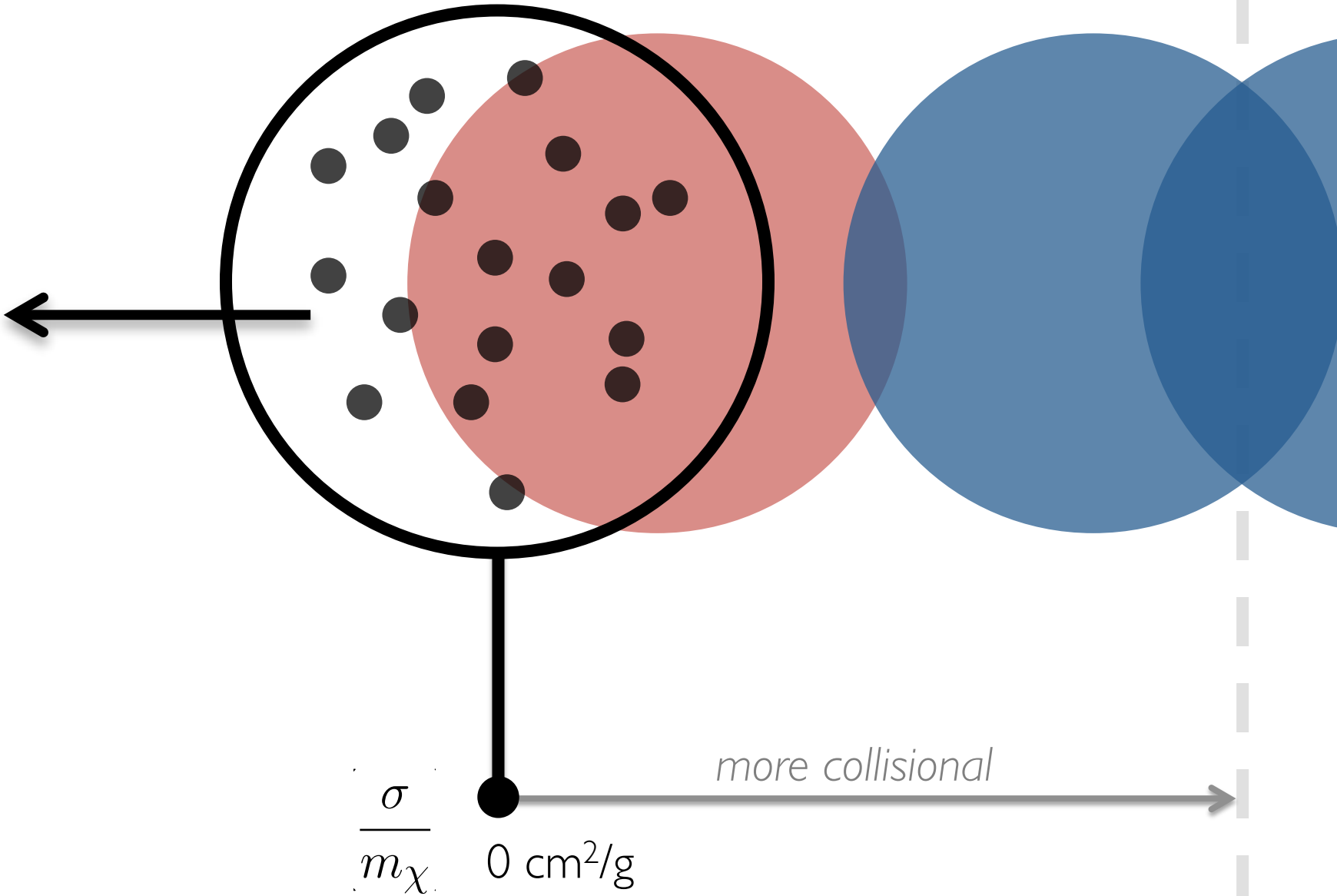


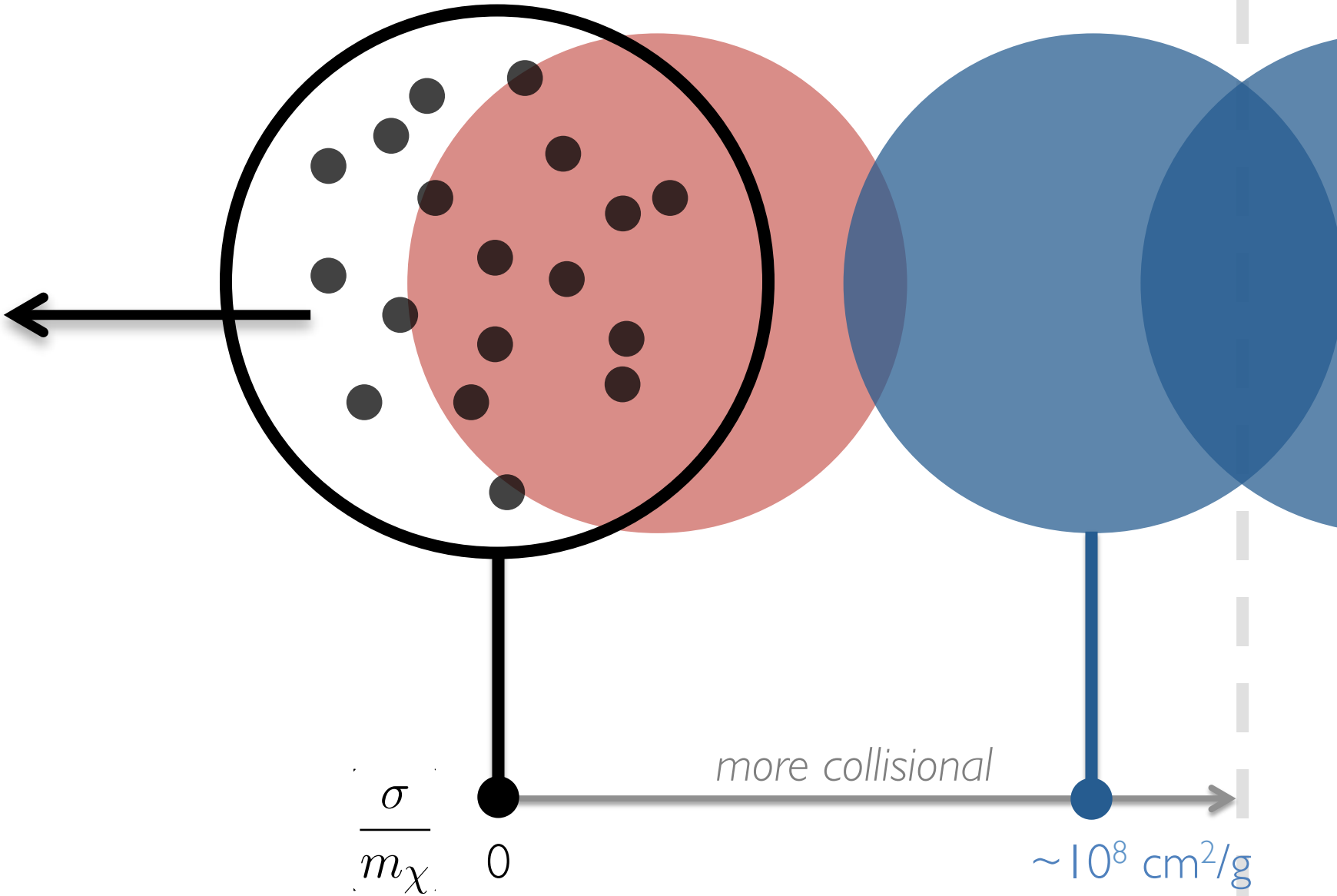
a galaxy cluster merger

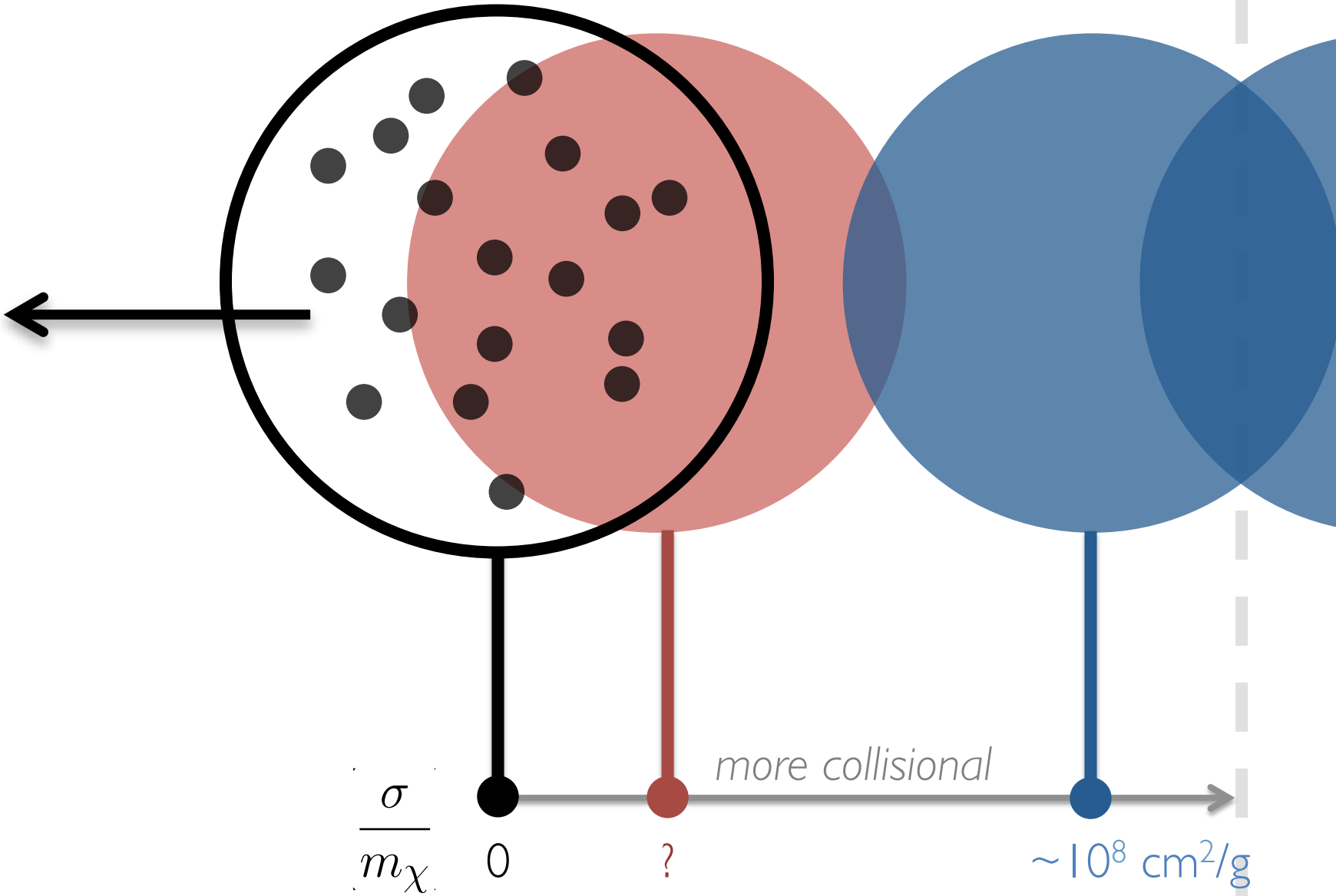




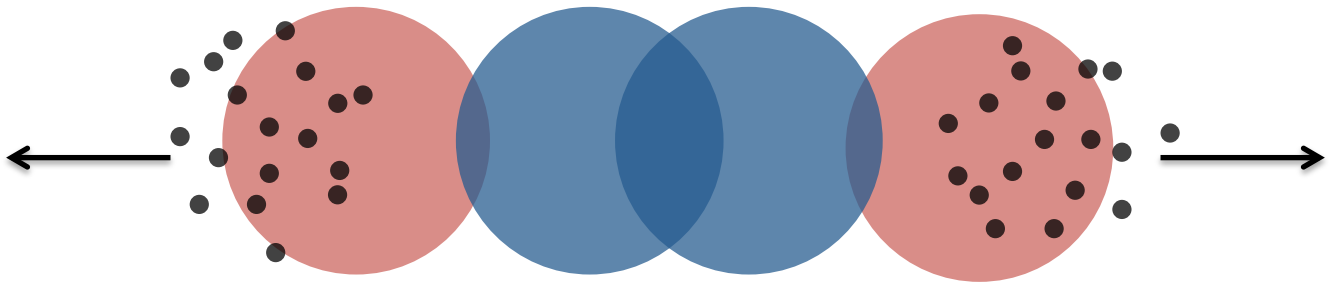

more collisional


more collisional
$\frac{\sigma}{m_\chi}$
0 cm^2/g


more collisional
$\frac{\sigma}{m_\chi}$
0
~10^8 cm^2/g

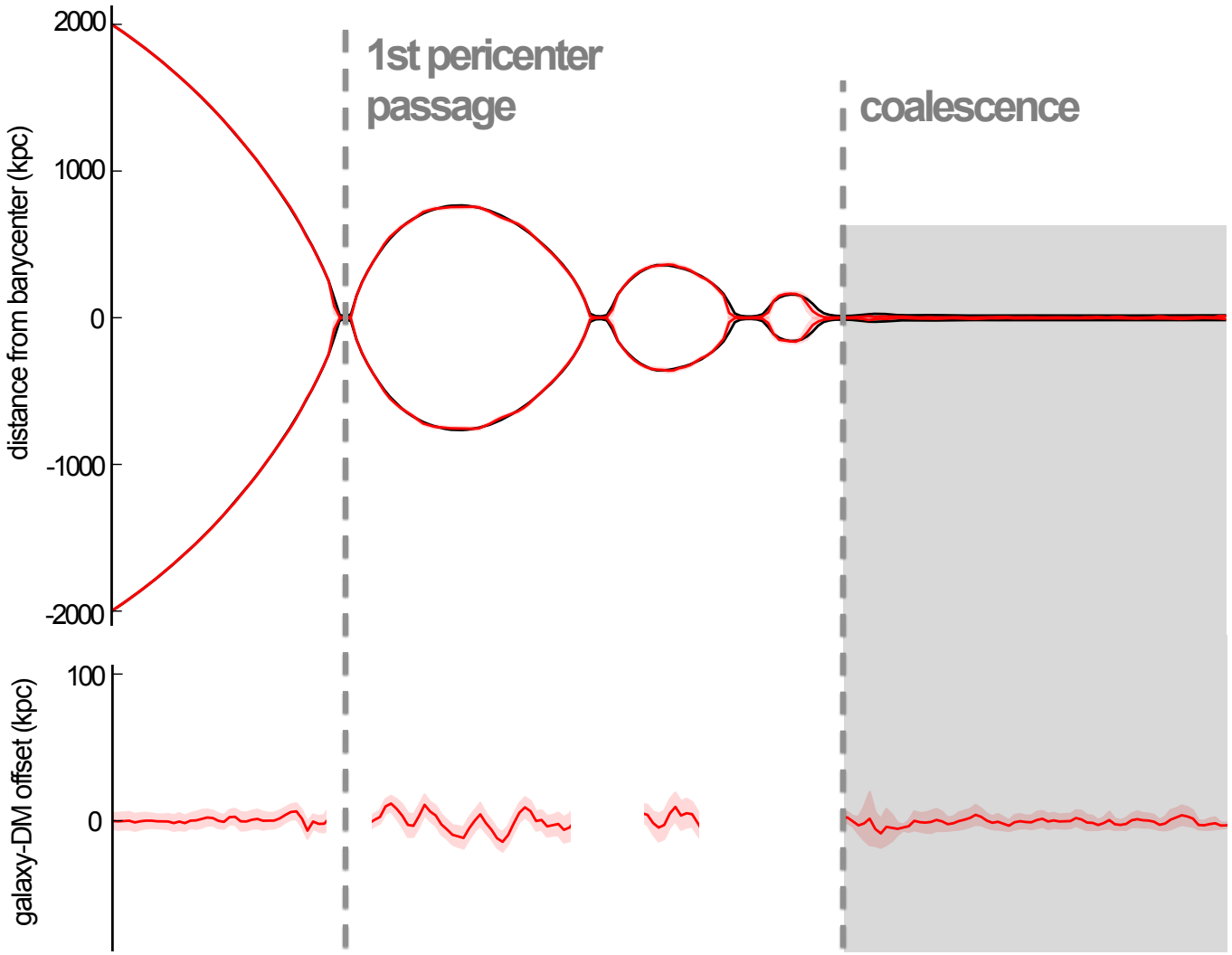

more collisional
$\frac{\sigma}{m_\chi}$
0
?
~10^8 cm^2/g

how do we get from



to $\frac{\sigma}{m_\chi}$?

to $\frac{\sigma}{m_\chi}$: the simulations

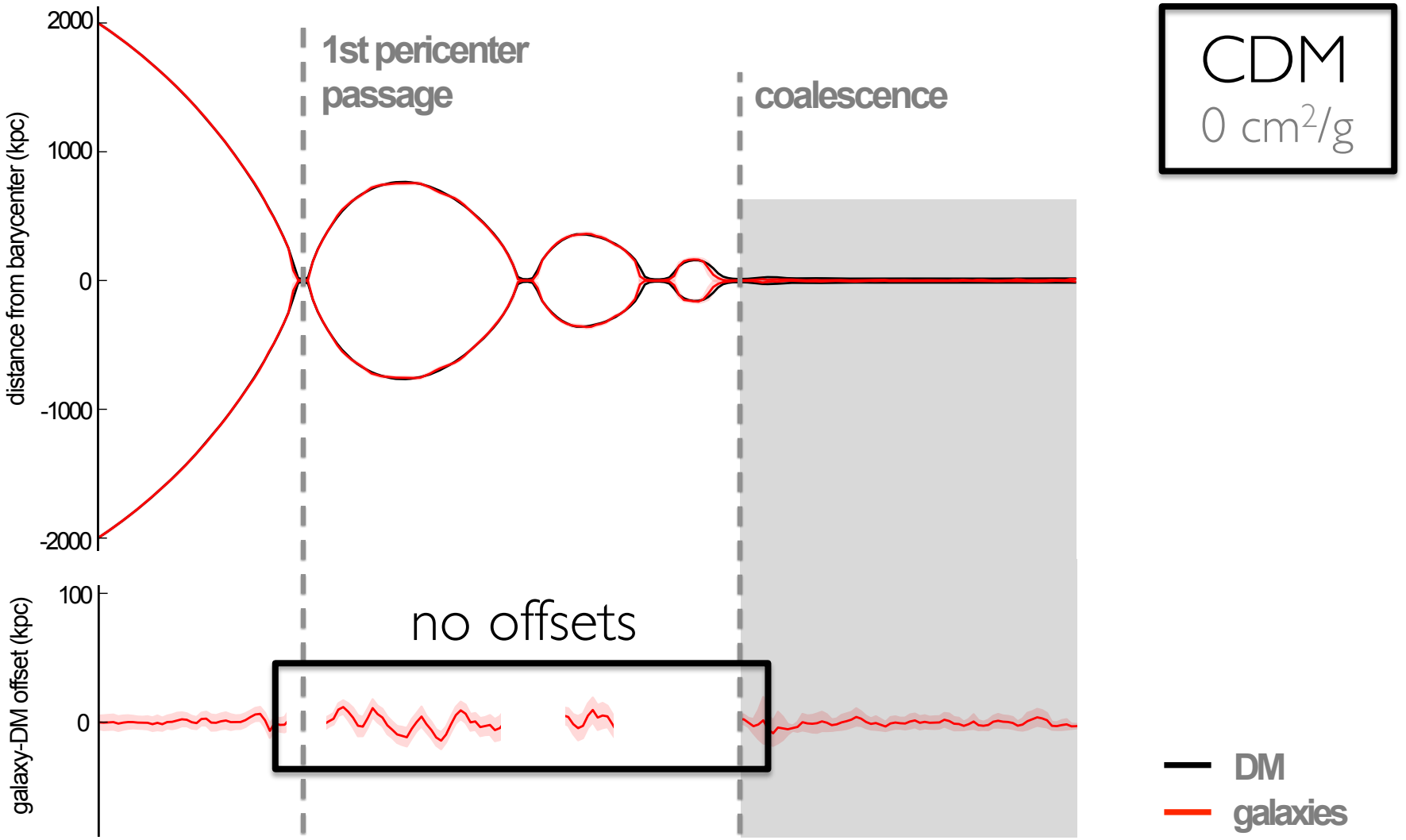


CDM
0 cm^2/g

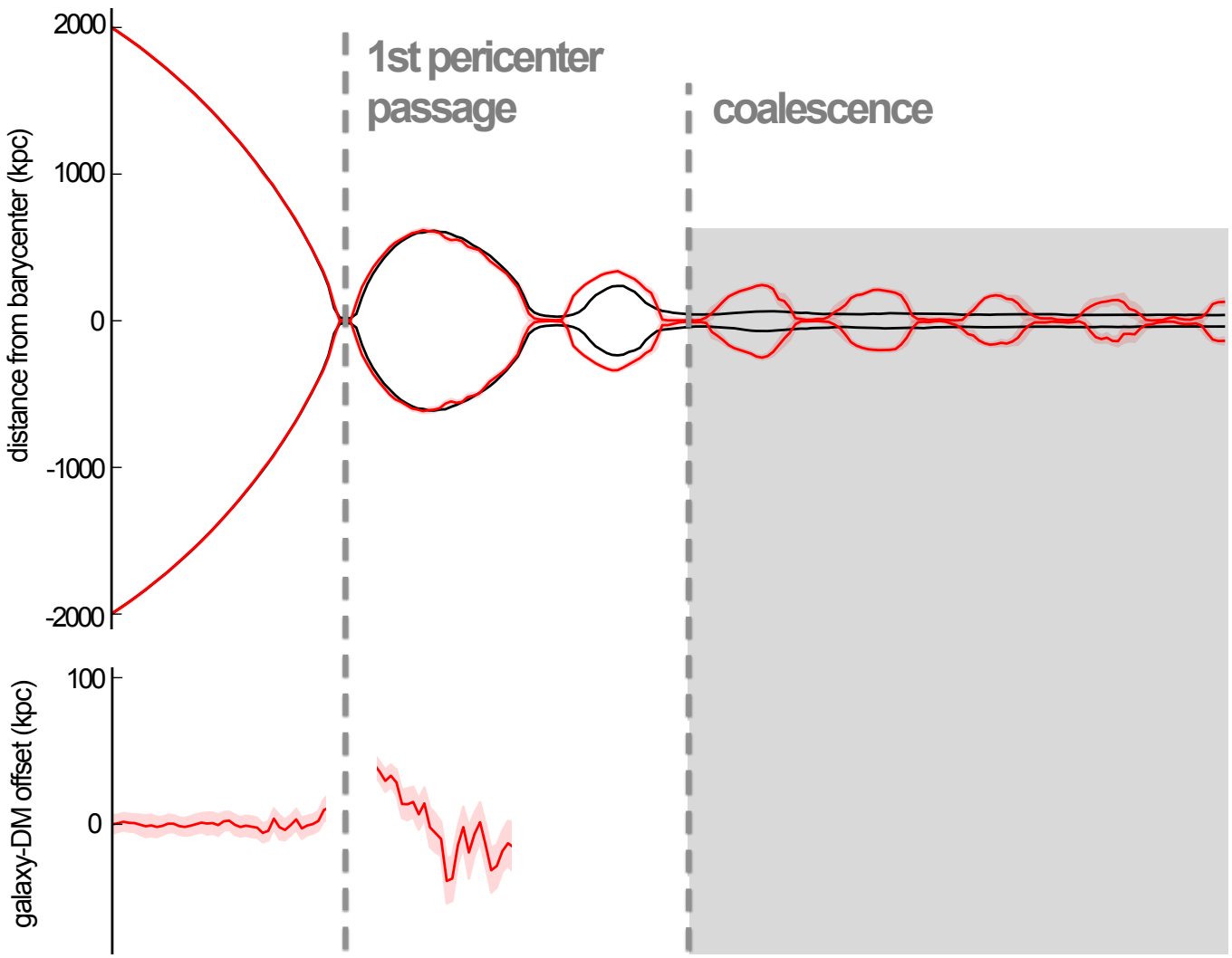
10^{15} $M_\odot$ equal mass mergers

DM
galaxies

to $\frac{\sigma}{m_\chi}$: the simulations



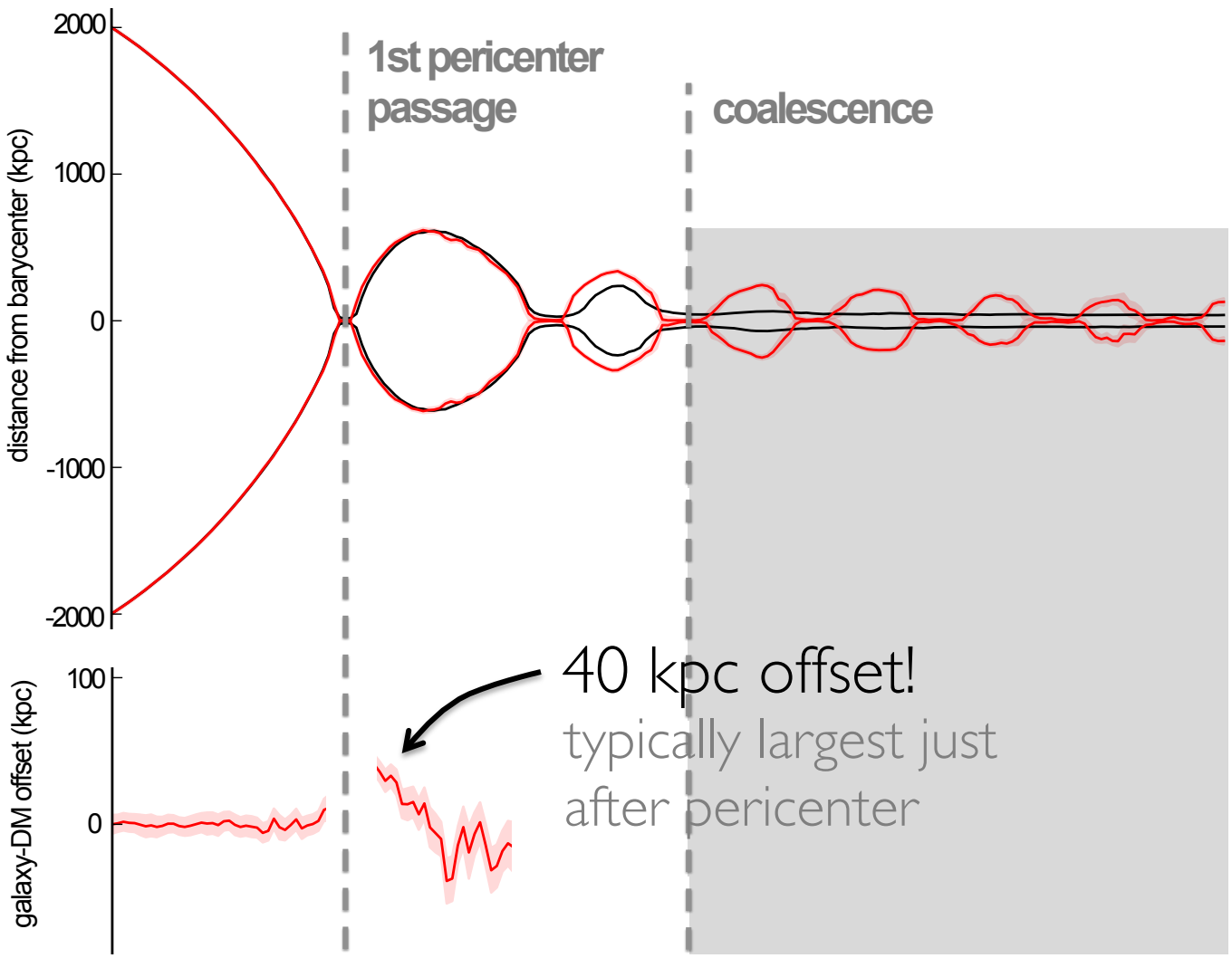
to $\frac{\sigma}{m_\chi}$: the simulations



SIDM
3 cm^2/g

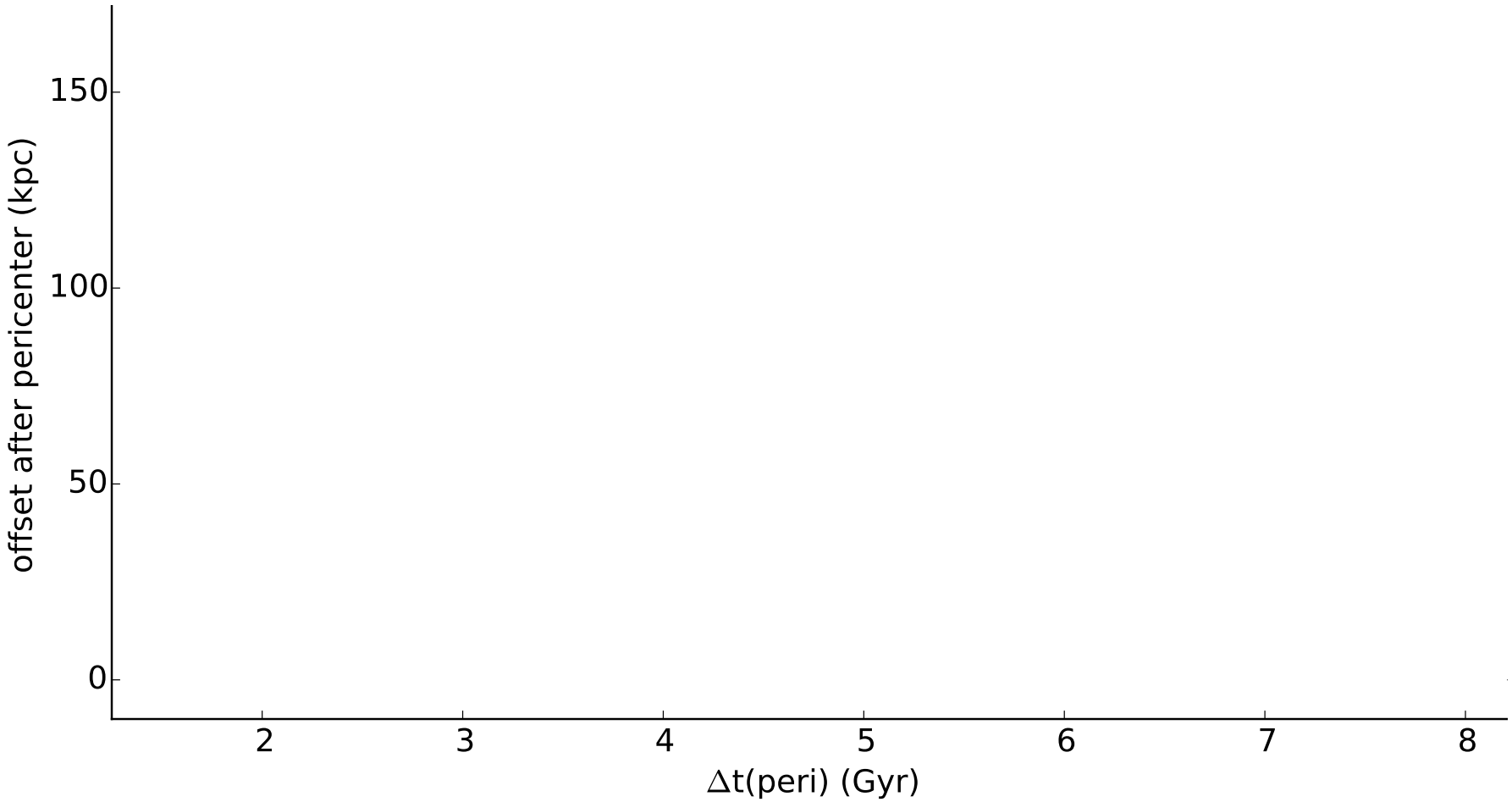
DM
galaxies

to $\frac{\sigma}{m_\chi}$: the simulations



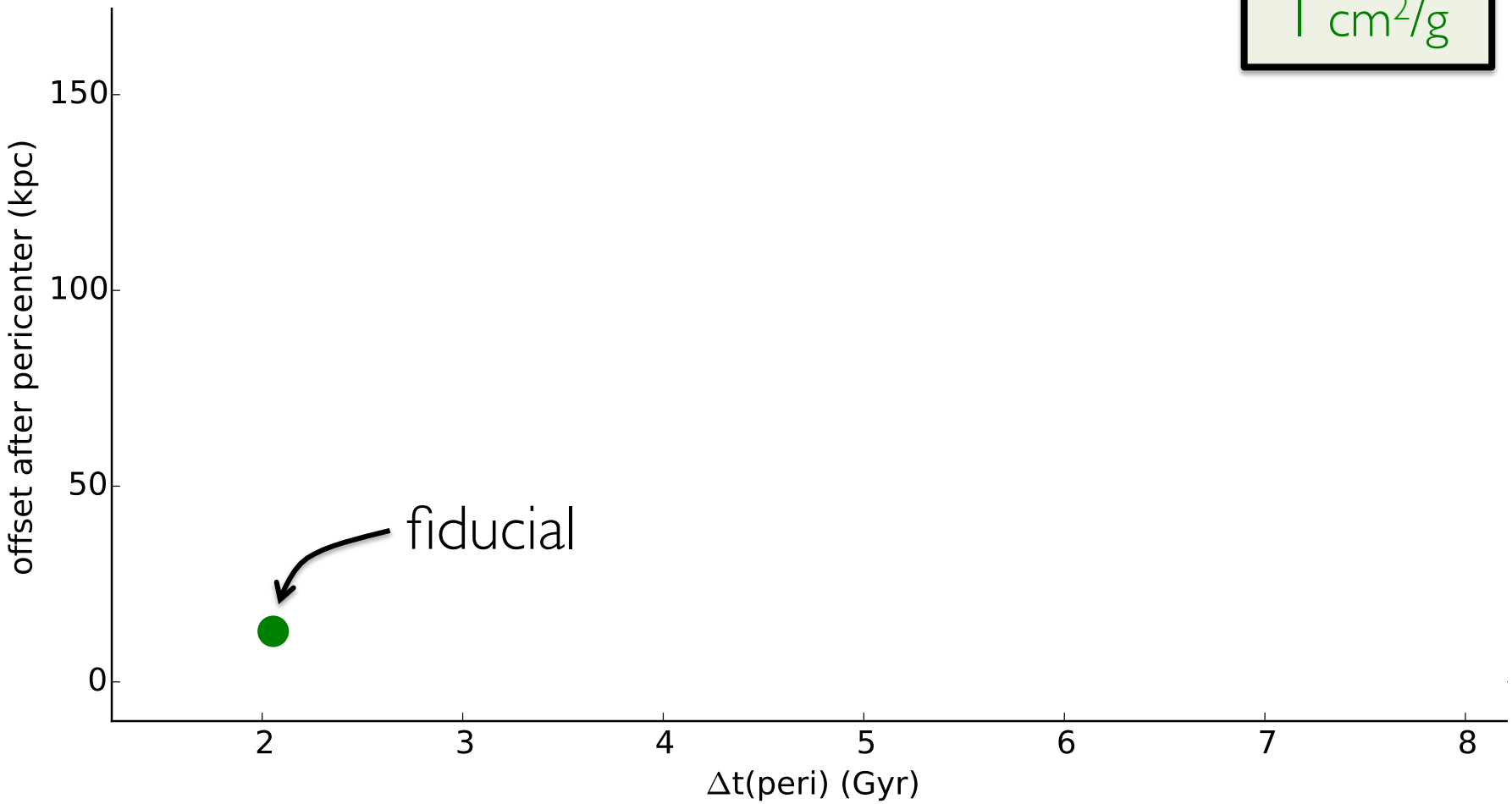
SIDM
3 cm^2/g

to $\frac{\sigma}{m_\chi}$: full simulation results

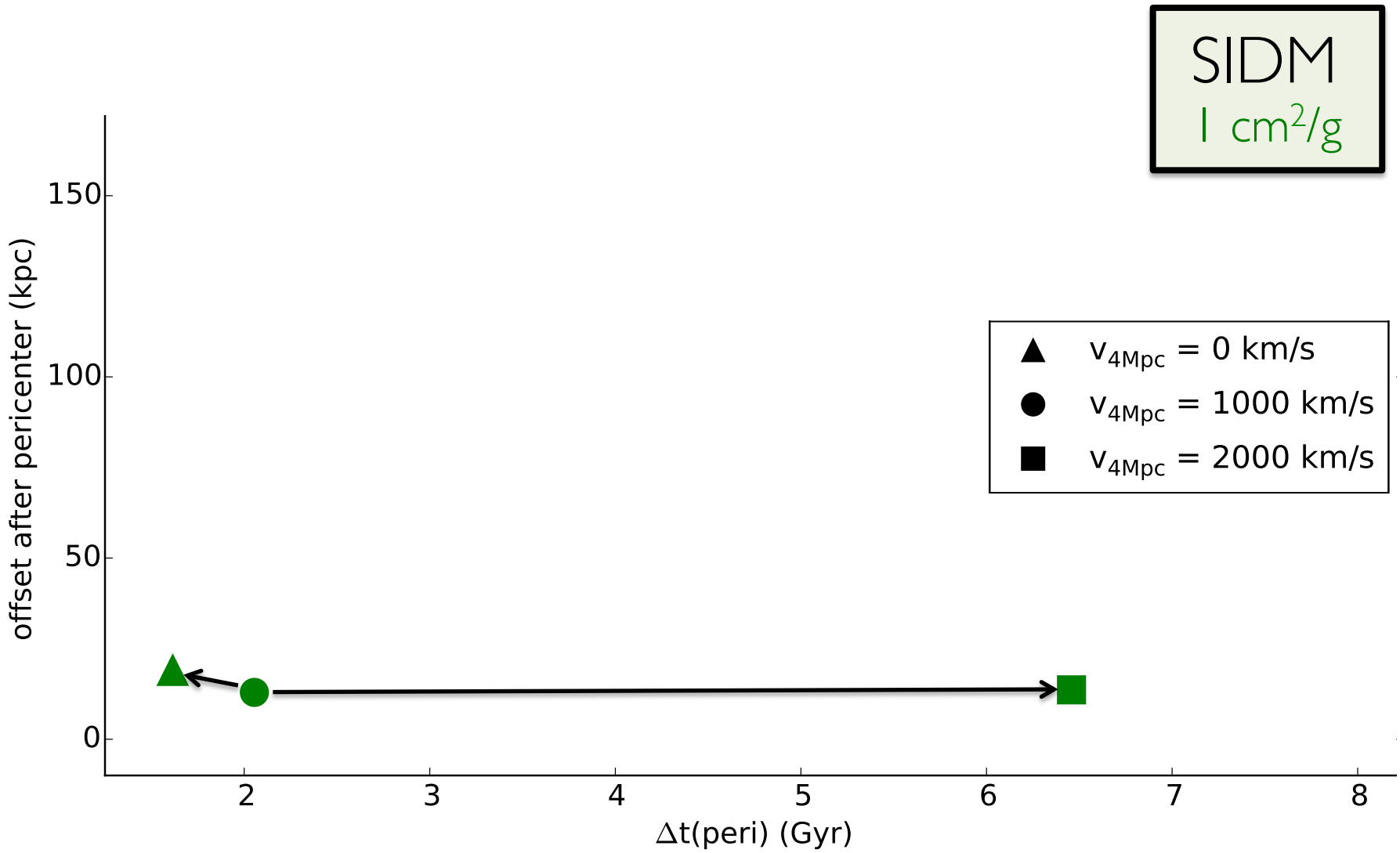


to $\frac{\sigma}{m_\chi}$: full simulation results

SIDM
1 cm^2/g



to $\frac{\sigma}{m_\chi}$: full simulation results



to $\frac{\sigma}{m_\chi}$: full simulation results

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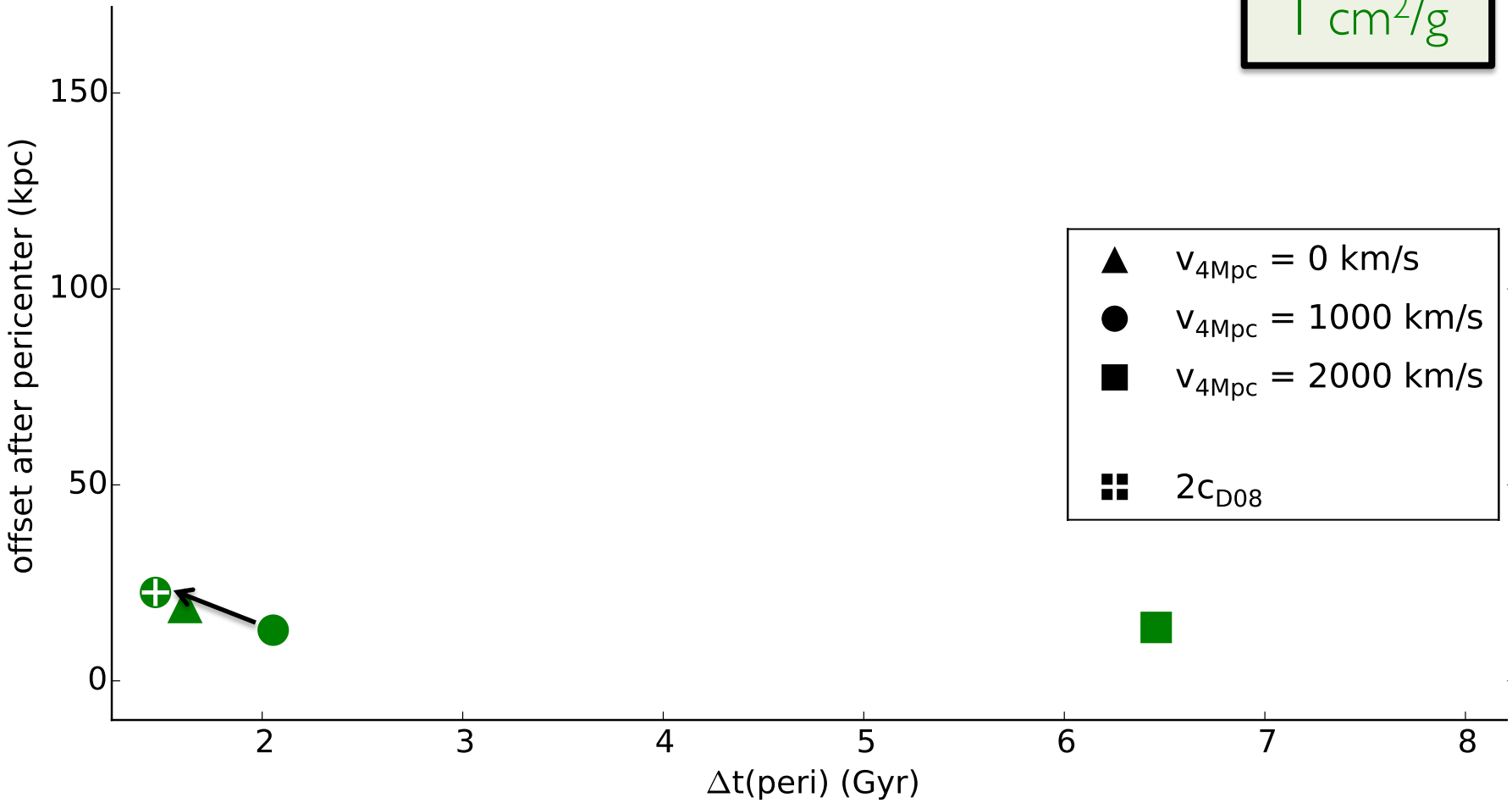
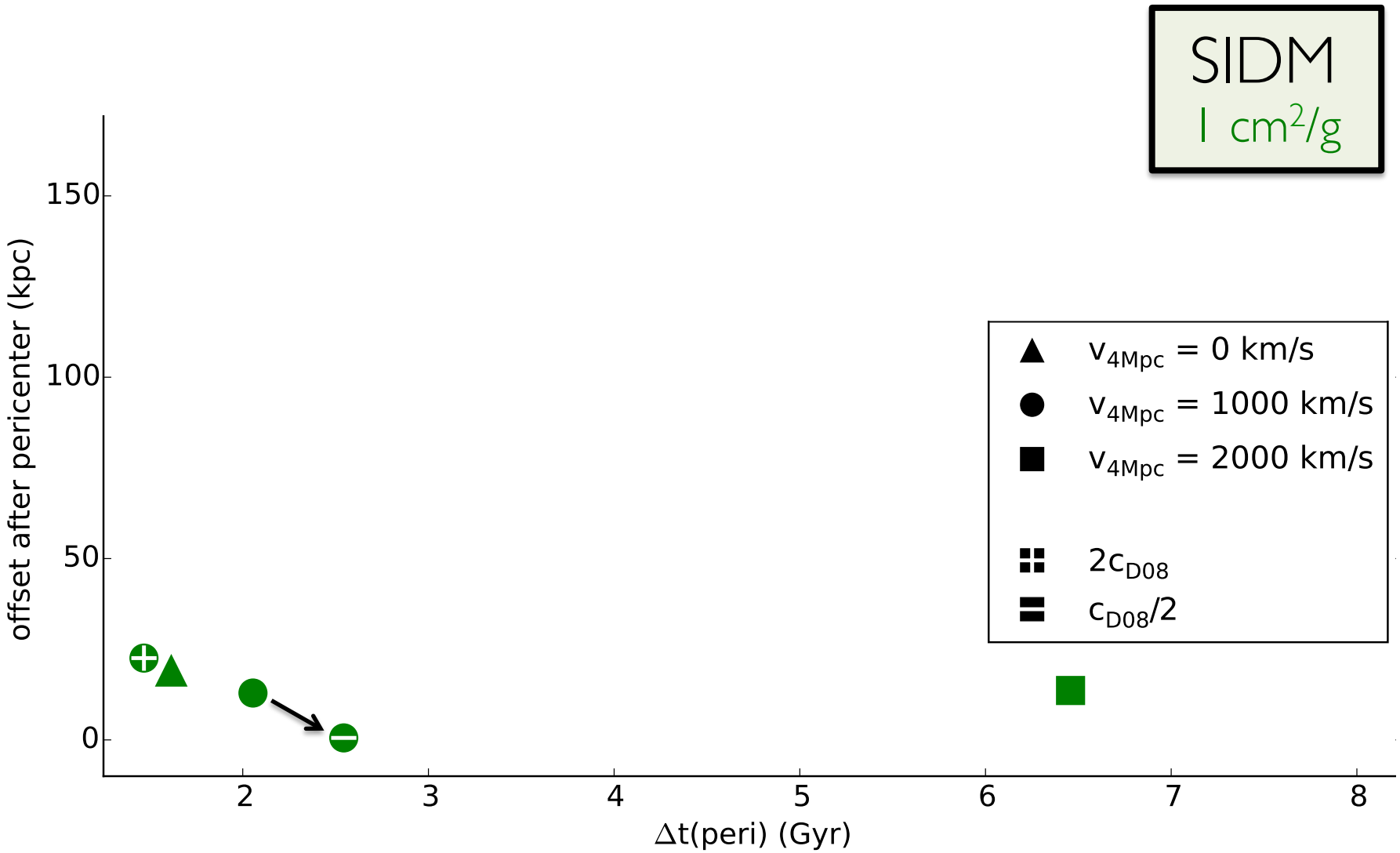
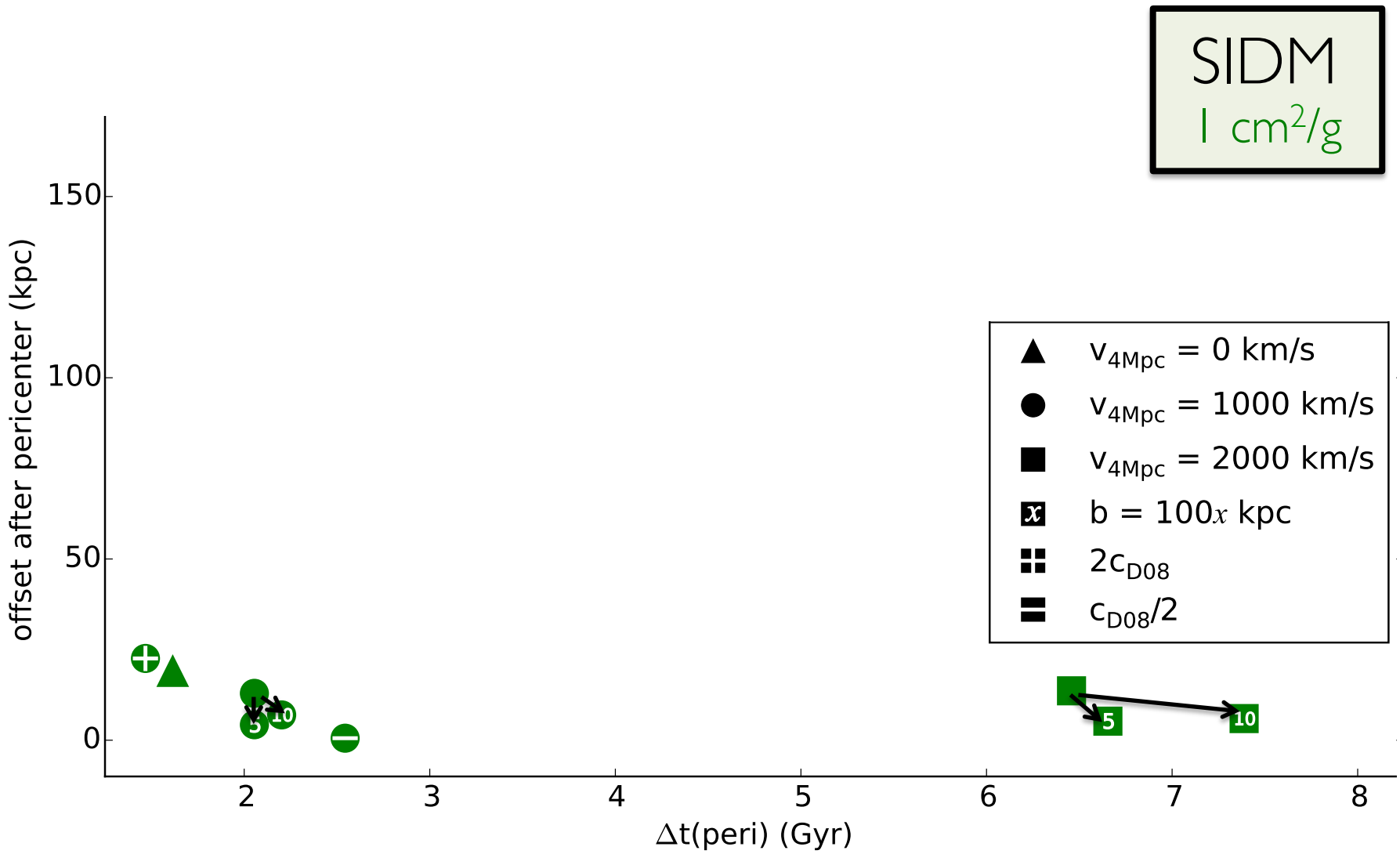
1 cm^2/g



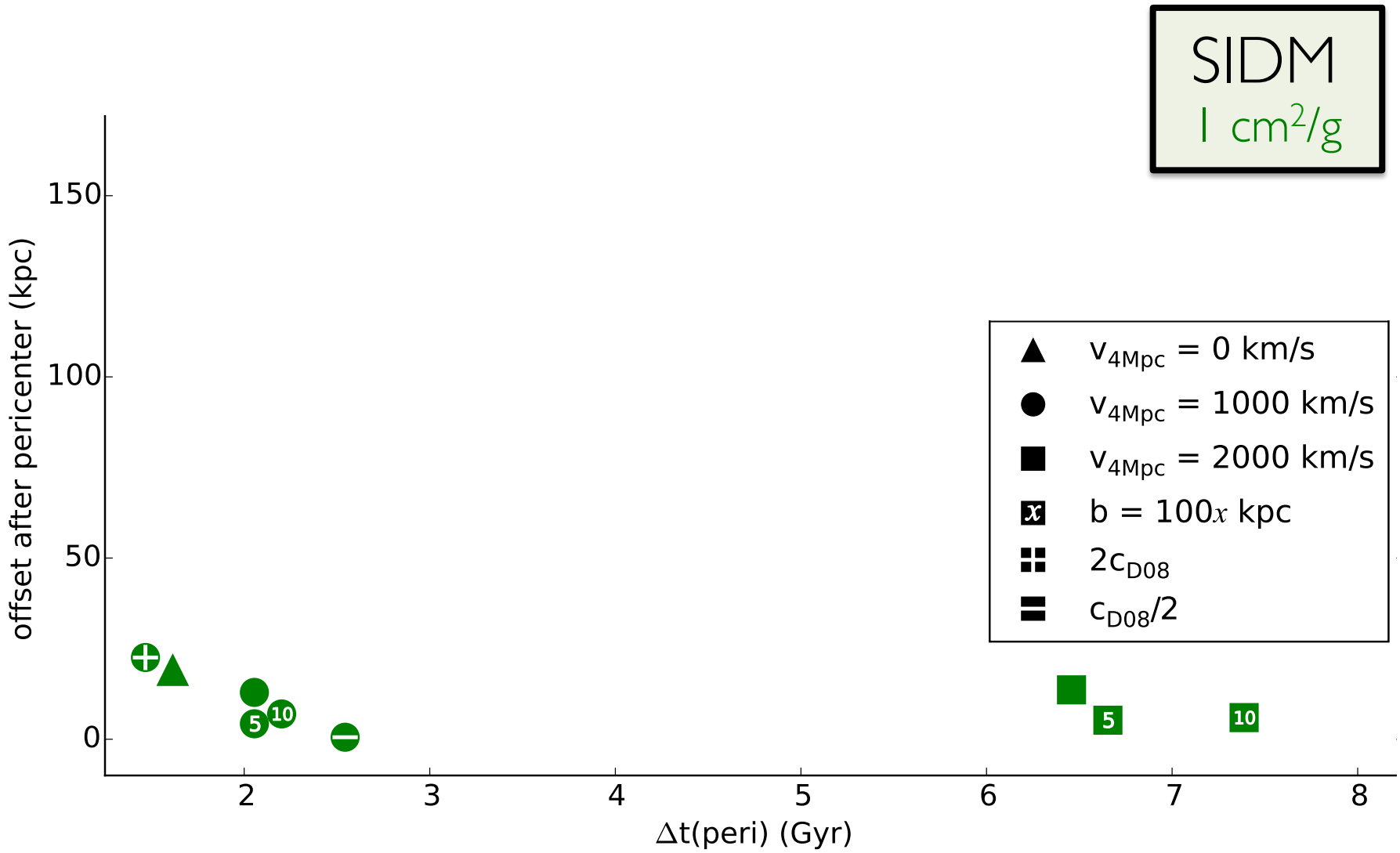
to $\frac{\sigma}{m_\chi}$: full simulation results



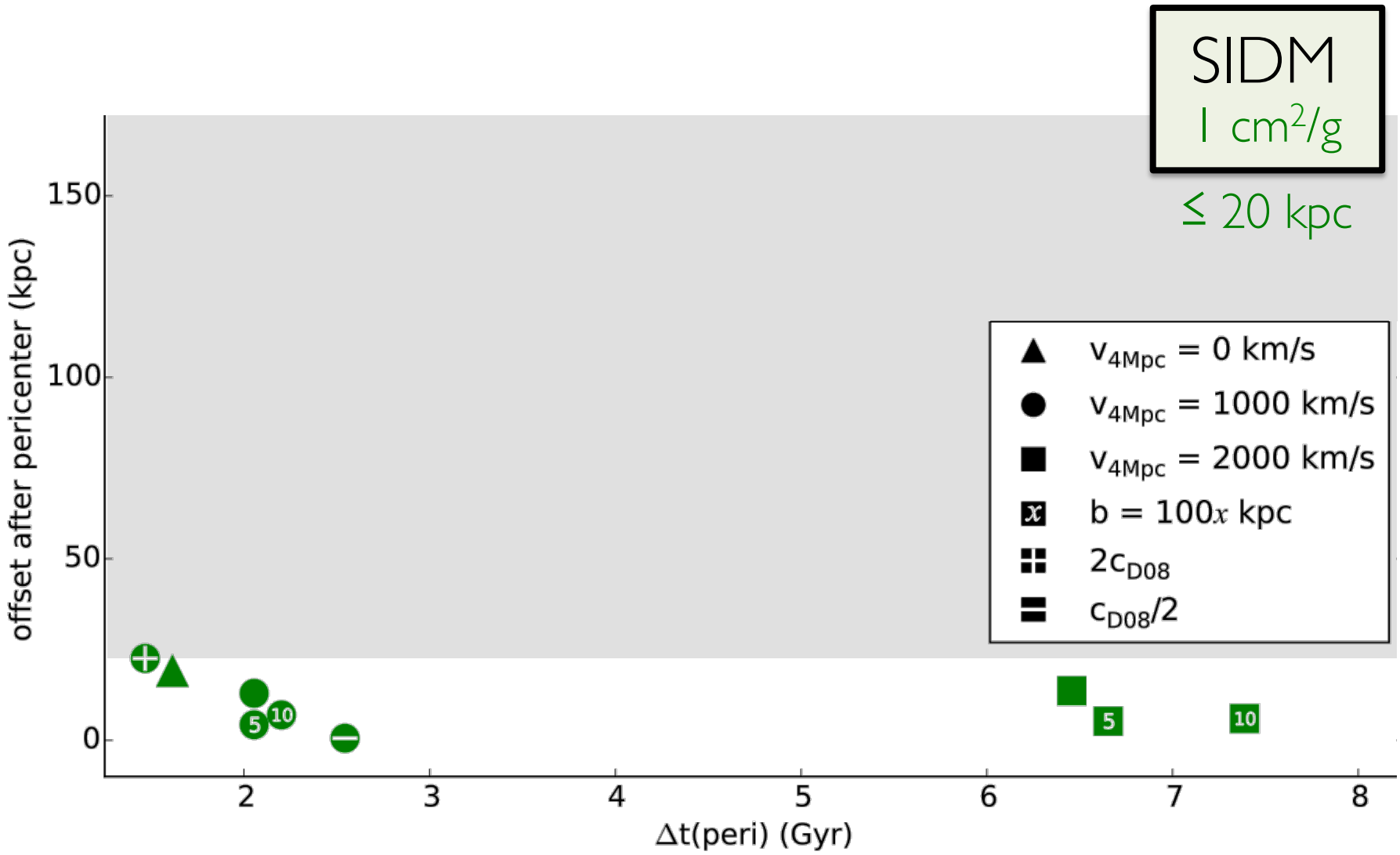
to $\frac{\sigma}{m_\chi}$: full simulation results



to $\frac{\sigma}{m_\chi}$: full simulation results



to $\frac{\sigma}{m_\chi}$: full simulation results



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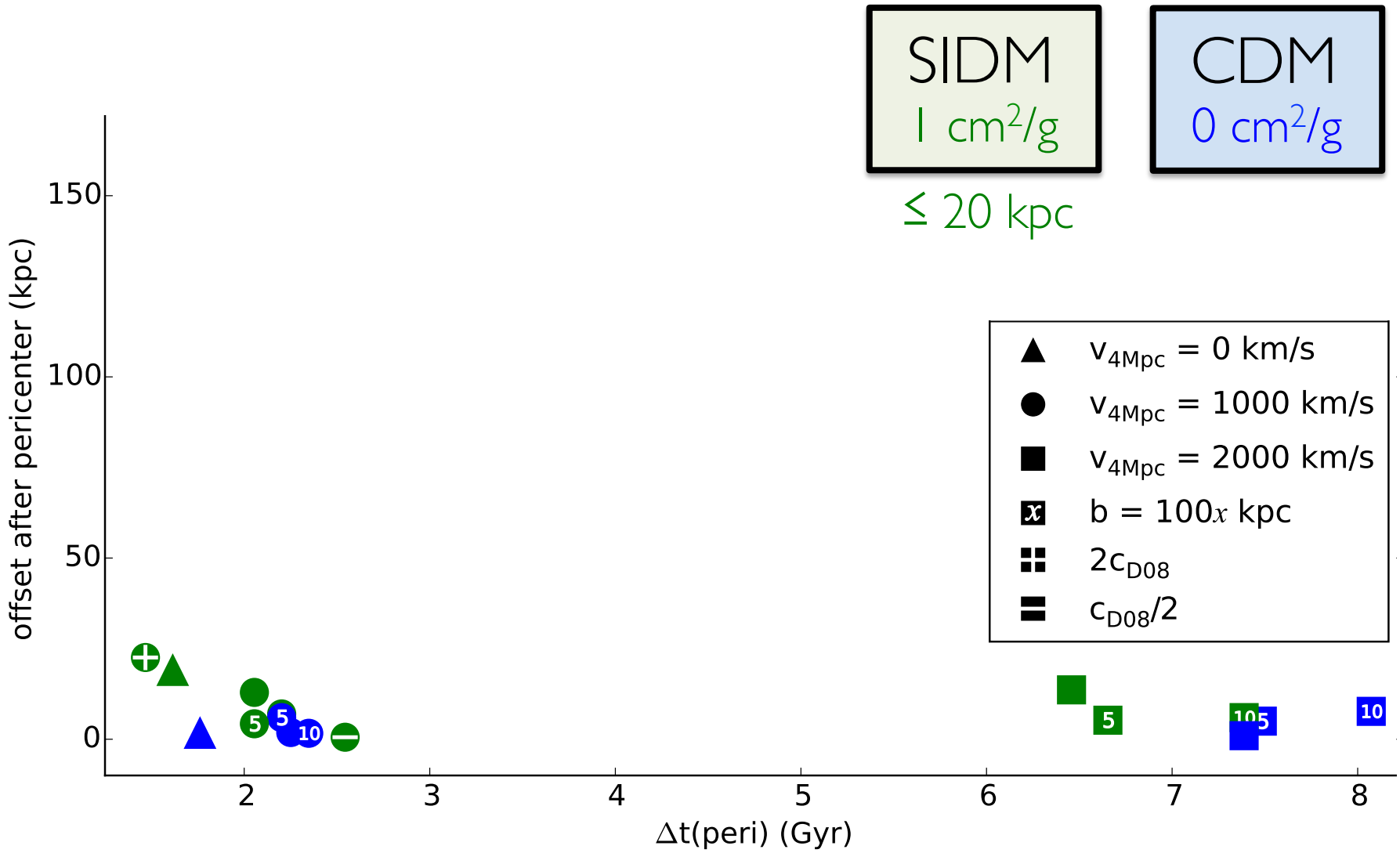
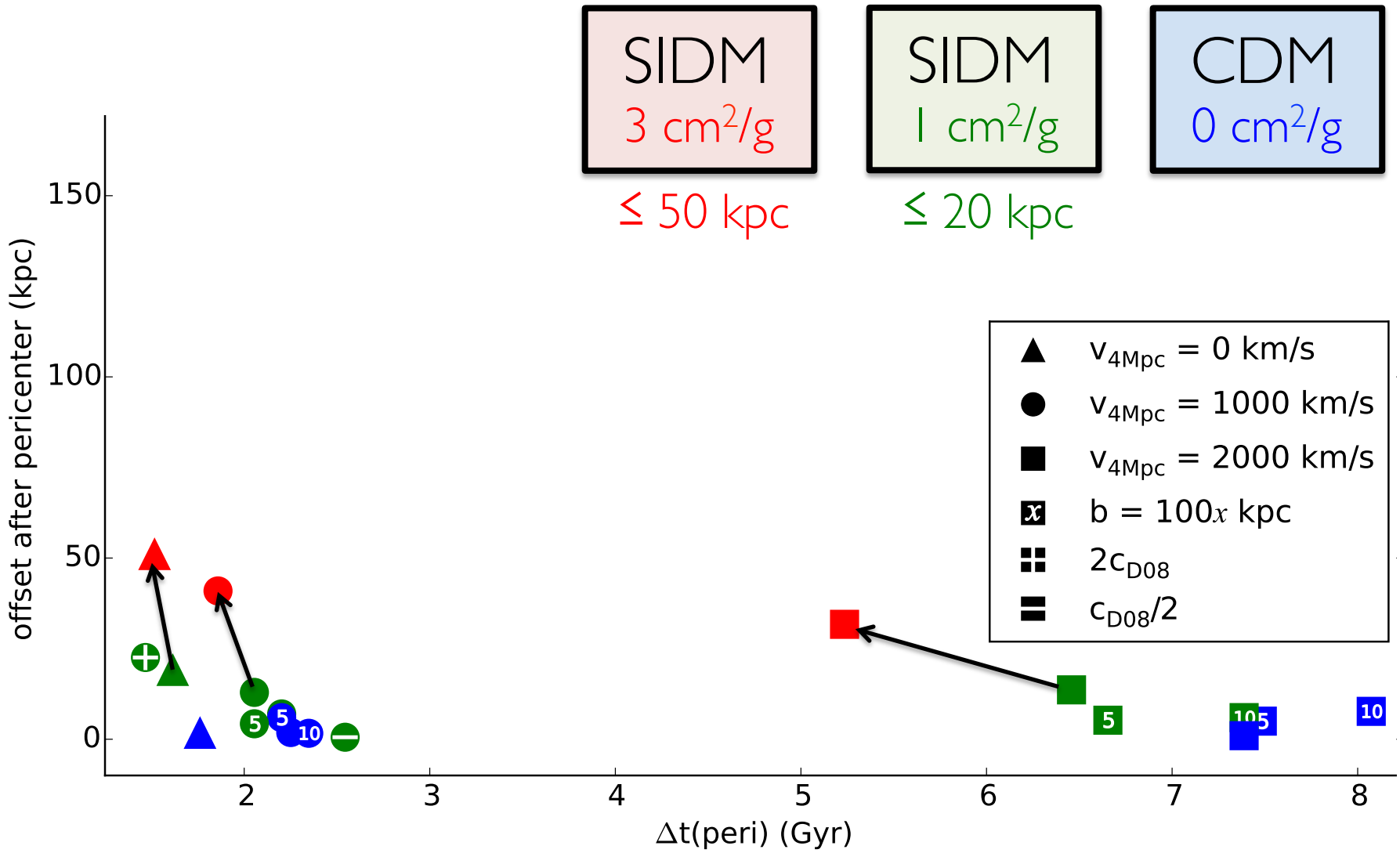
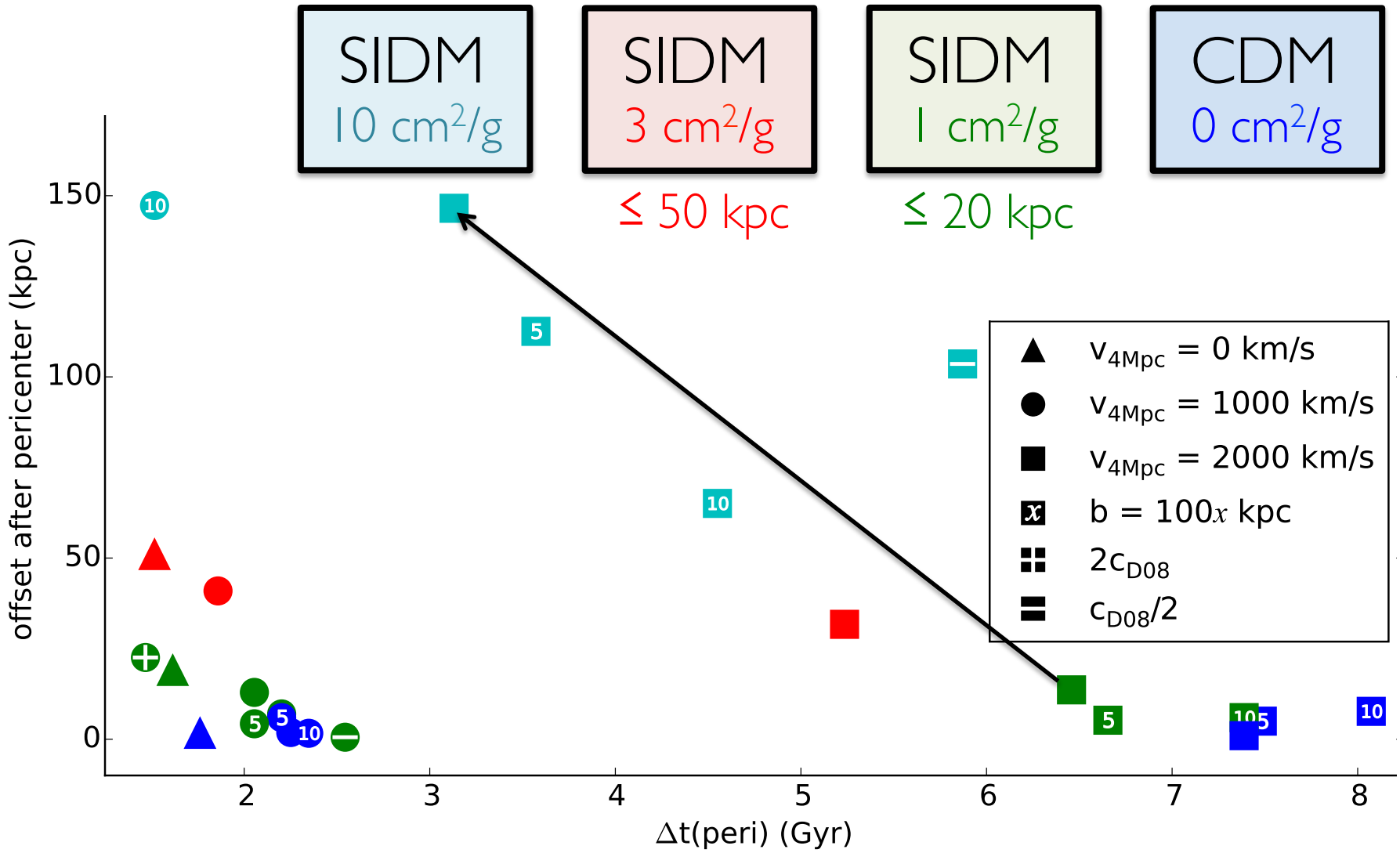


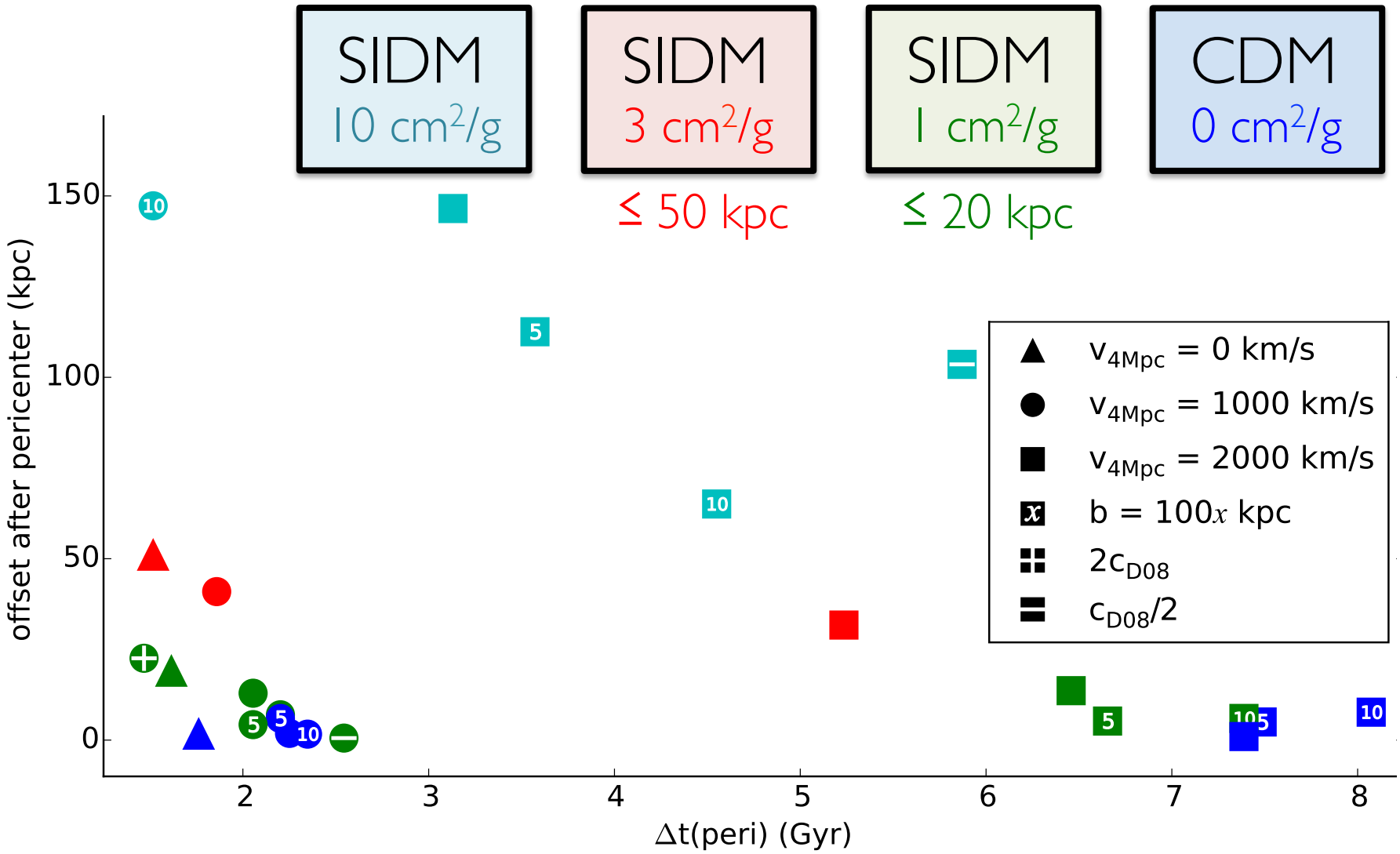
to $\frac{\sigma}{m_\chi}$: full simulation results



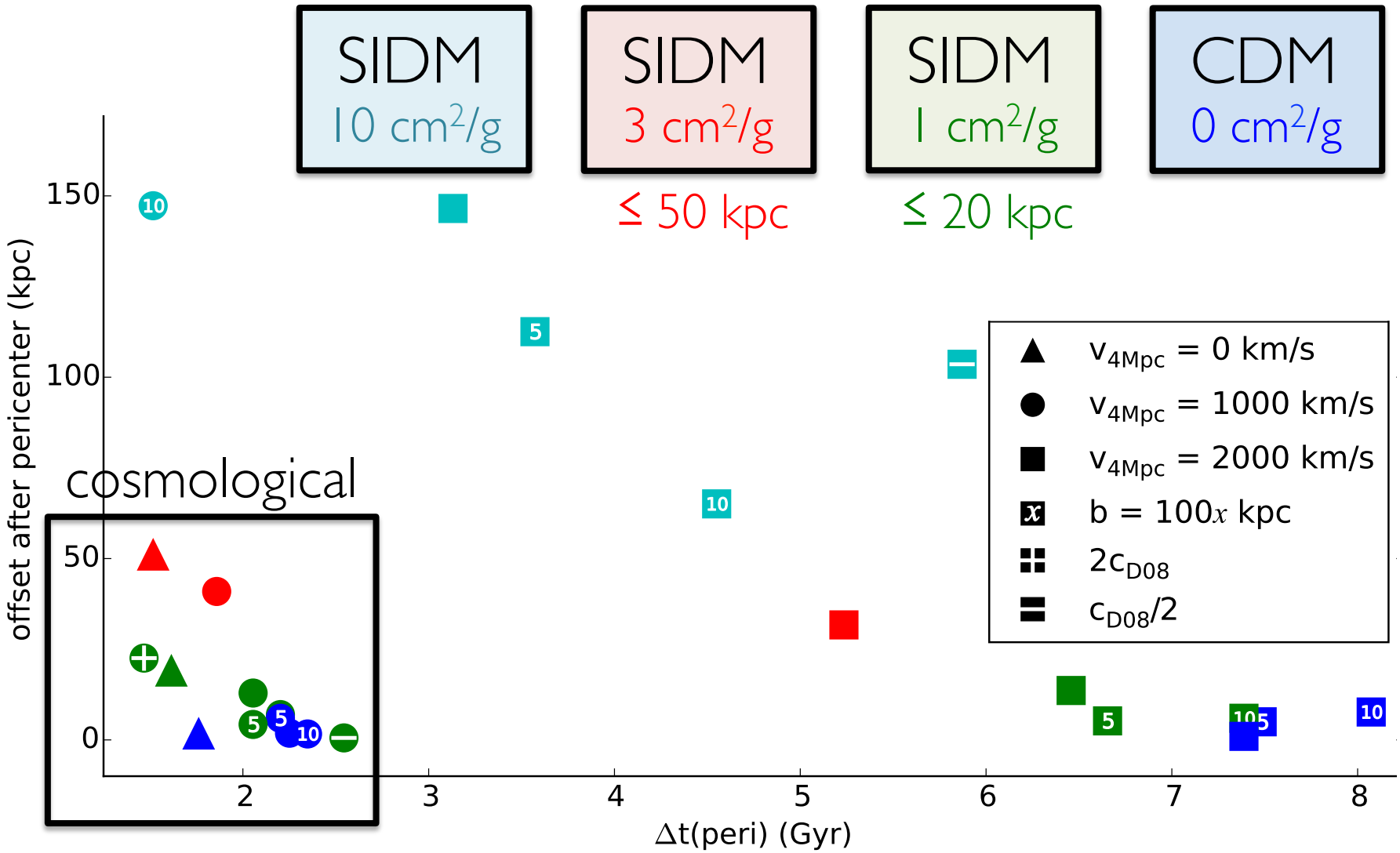
to $\frac{\sigma}{m_\chi}$: full simulation results



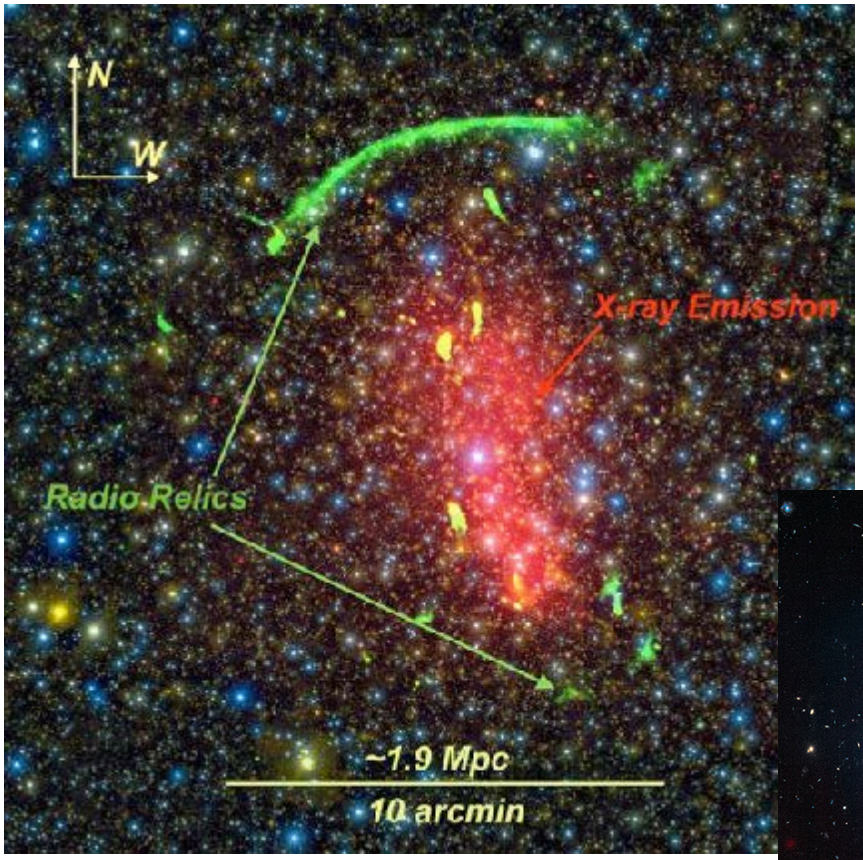
to $\frac{\sigma}{m_\chi}$: full simulation results



to $\frac{\sigma}{m_\chi}$: full simulation results



to $\frac{\sigma}{m_\chi}$: the observations



Sausage Cluster

160 ±130 kpc

220 ± 240 kpc

El Gordo

100, 400 (± 140?) kpc

equal mass mergers: a summary

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expected offsets are $\leq$ 20-50 kpc

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(smaller than obs. uncertainties +
too small to explain observed offsets)

equal mass mergers: a summary

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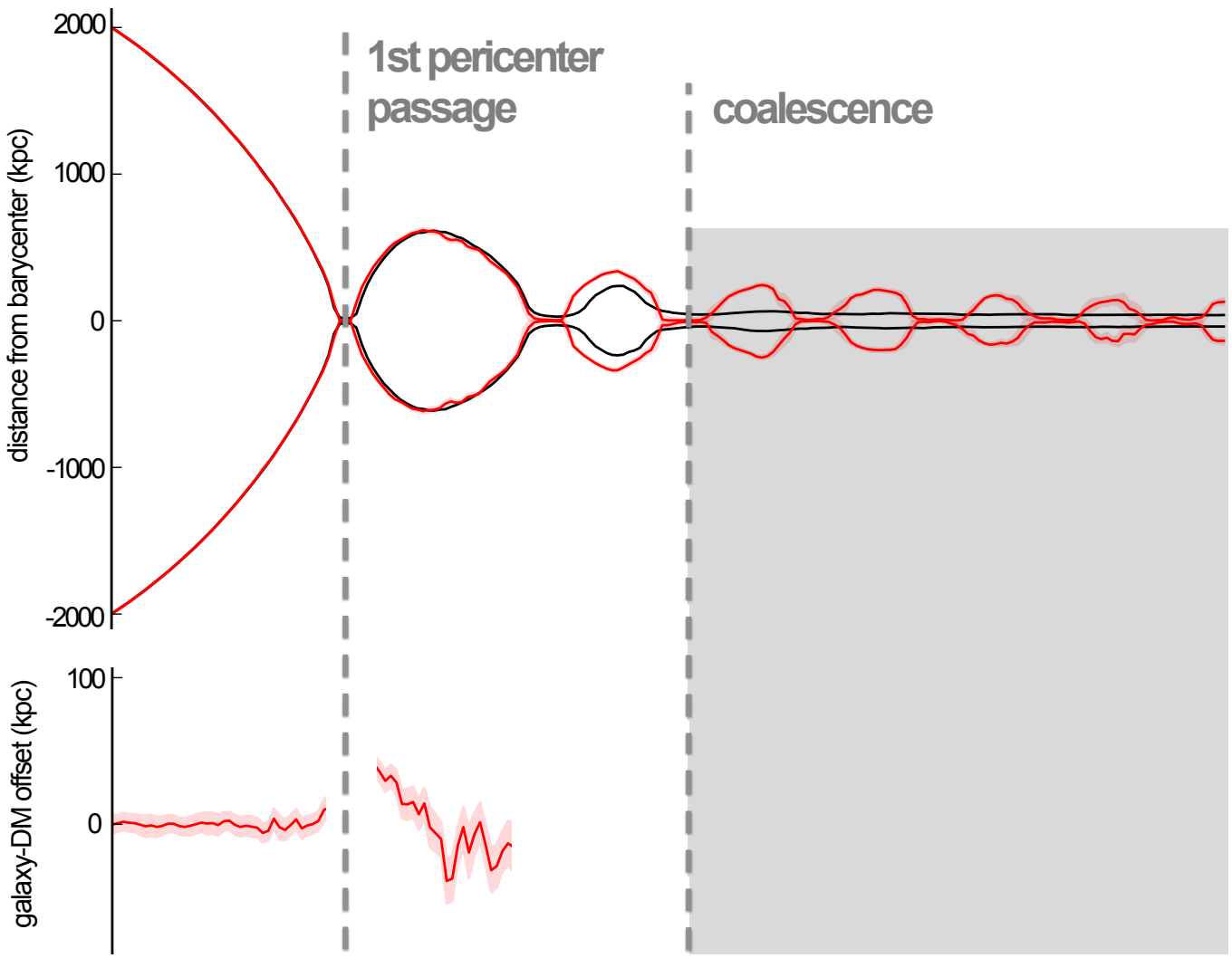
however…

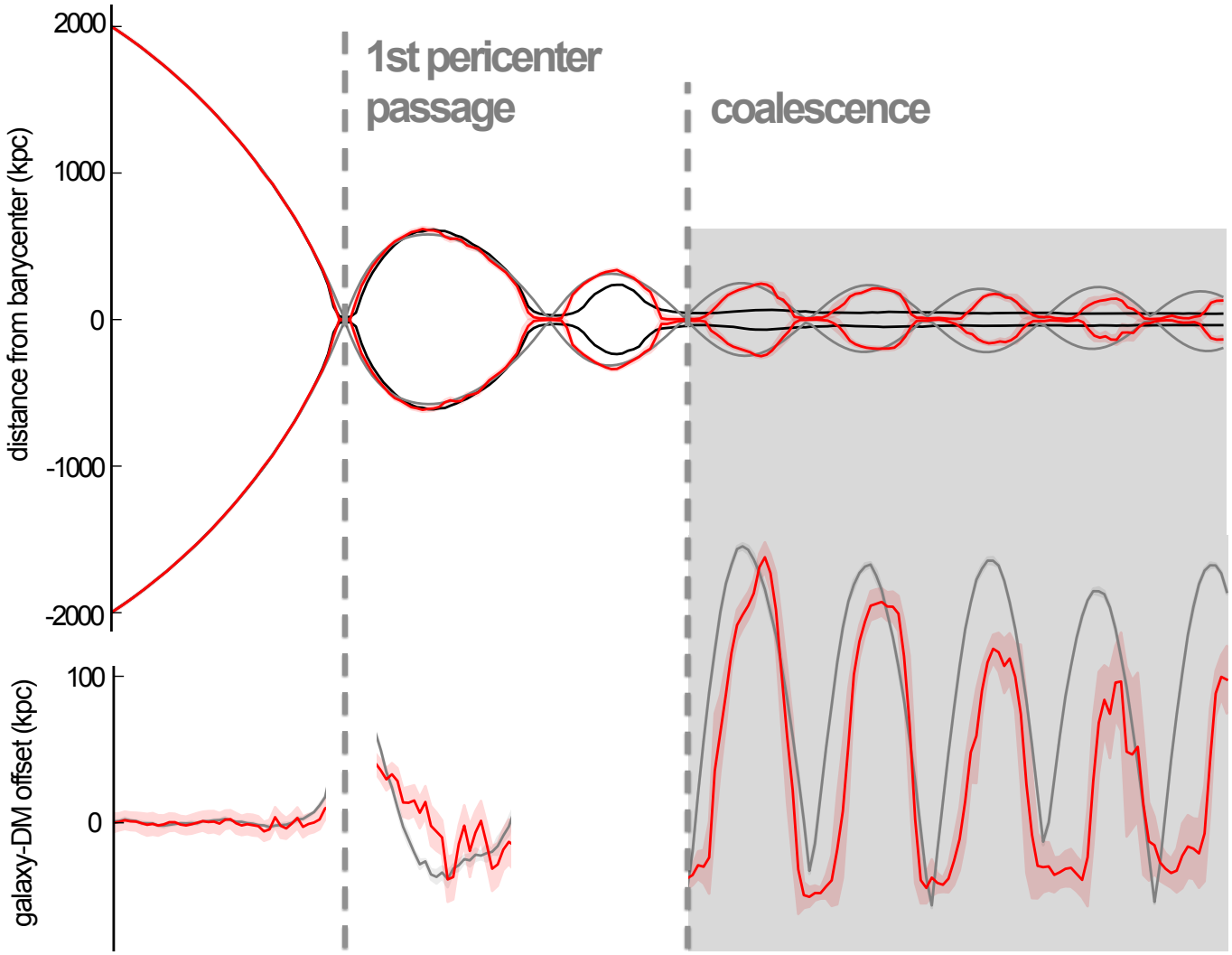
to $\frac{\sigma}{m_\chi}$: alternative constraints?



SIDM
3 cm^2/g

DM
galaxies

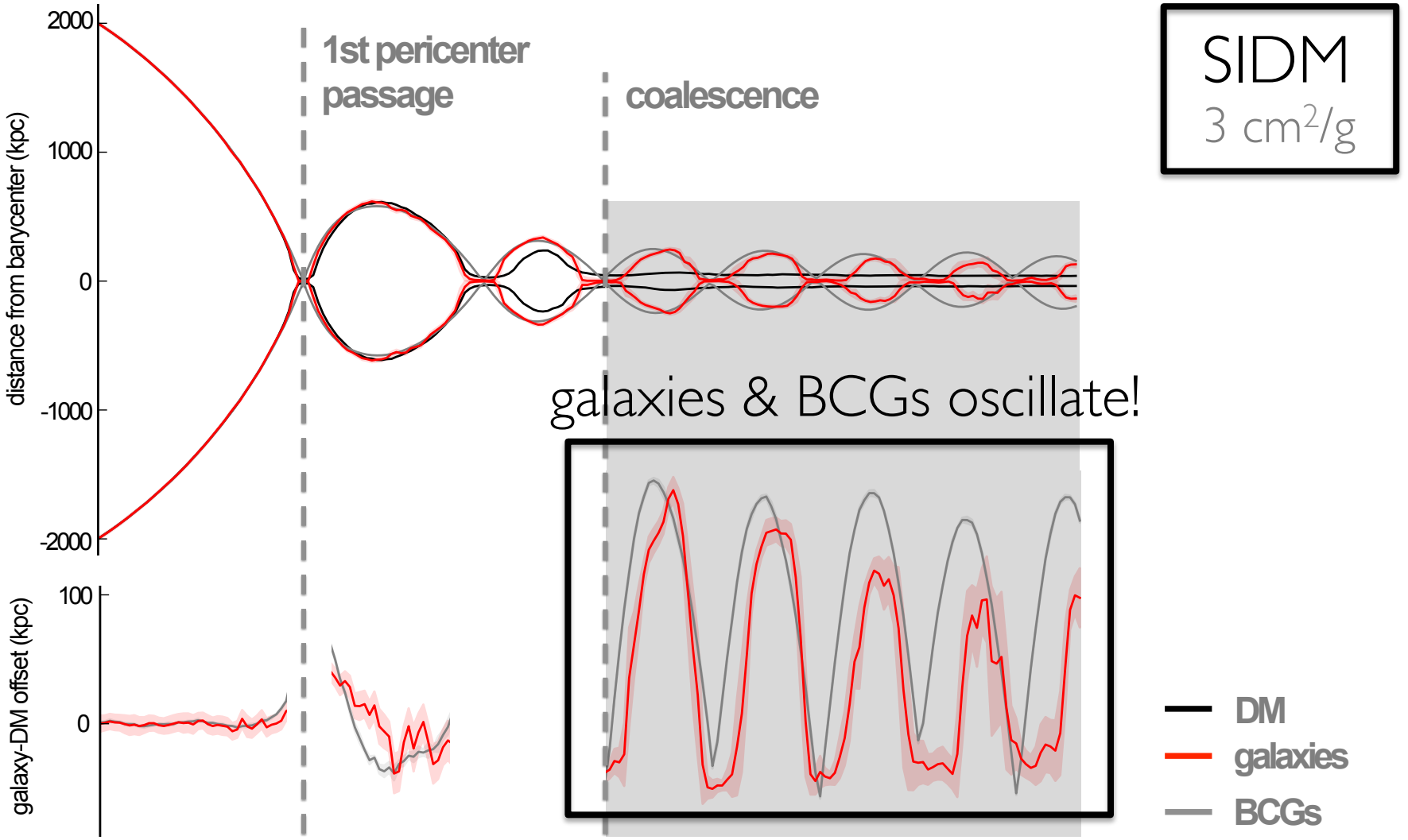
to $\frac{\sigma}{m_\chi}$: alternative constraints?



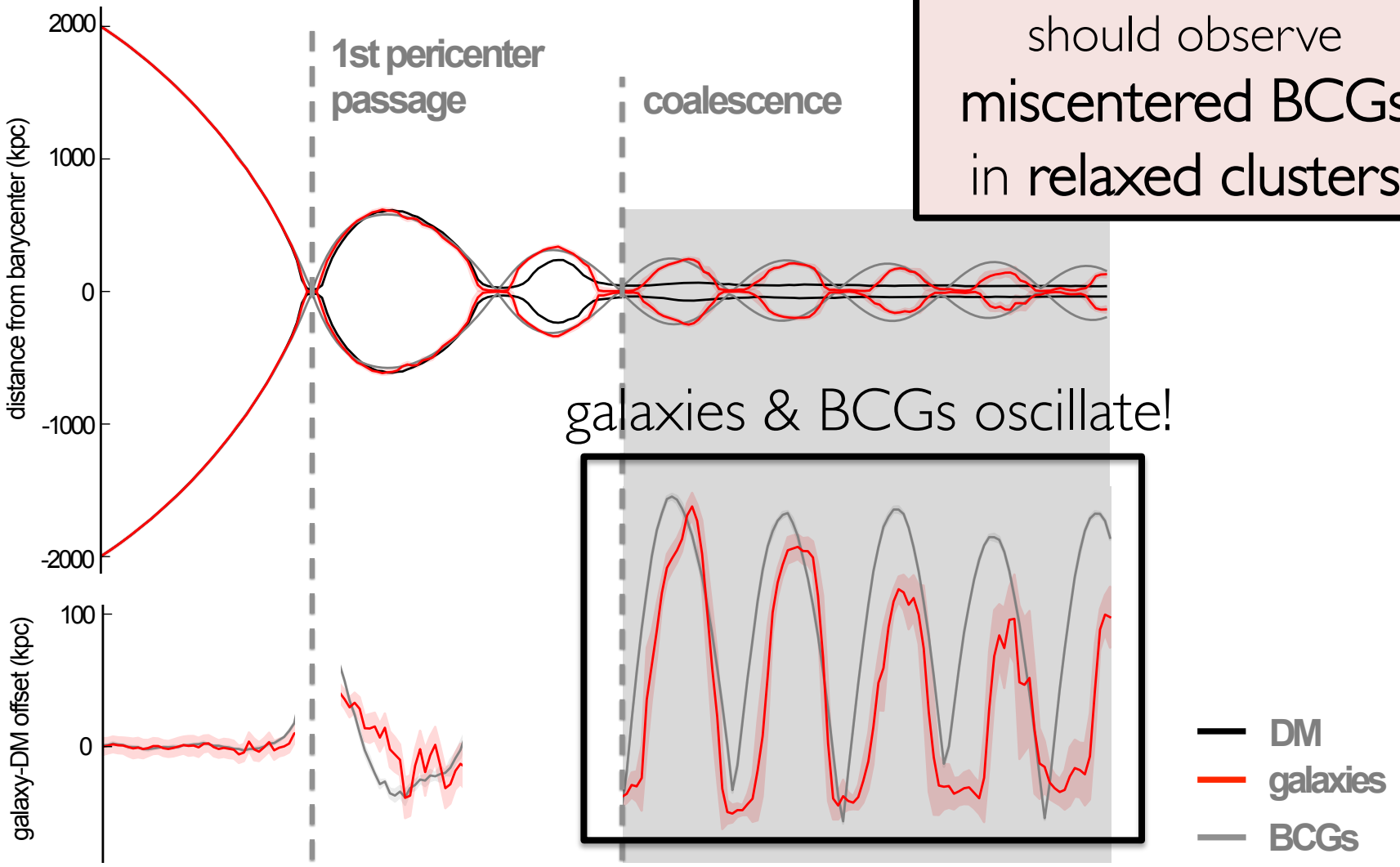
SIDM
3 cm^2/g

DM
galaxies
BCGs

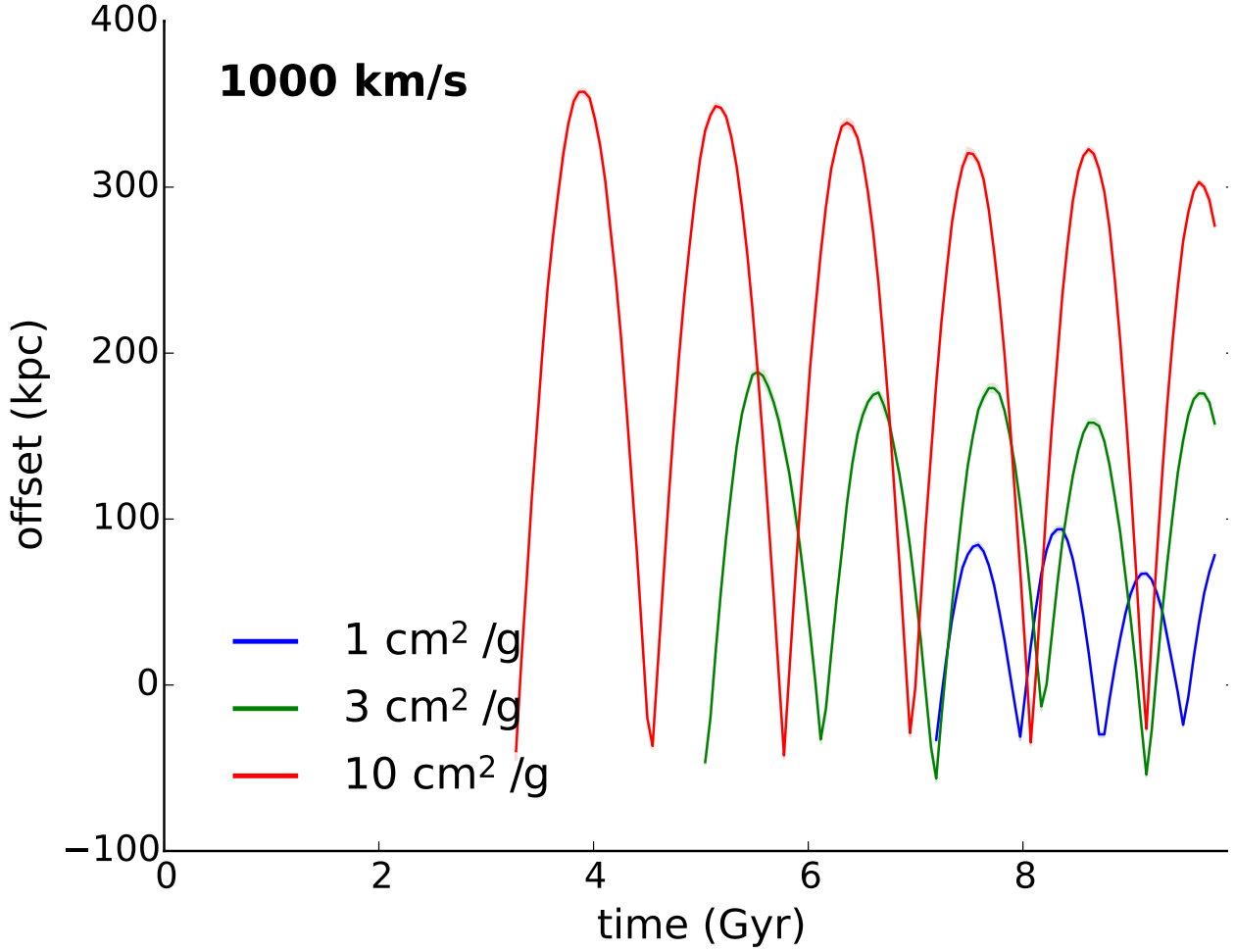
to $\frac{\sigma}{m_\chi}$: alternative constraints?



to $\frac{\sigma}{m_\chi}$: alternative constraints?



to $\frac{\sigma}{m_\chi}$: alternative constraints?

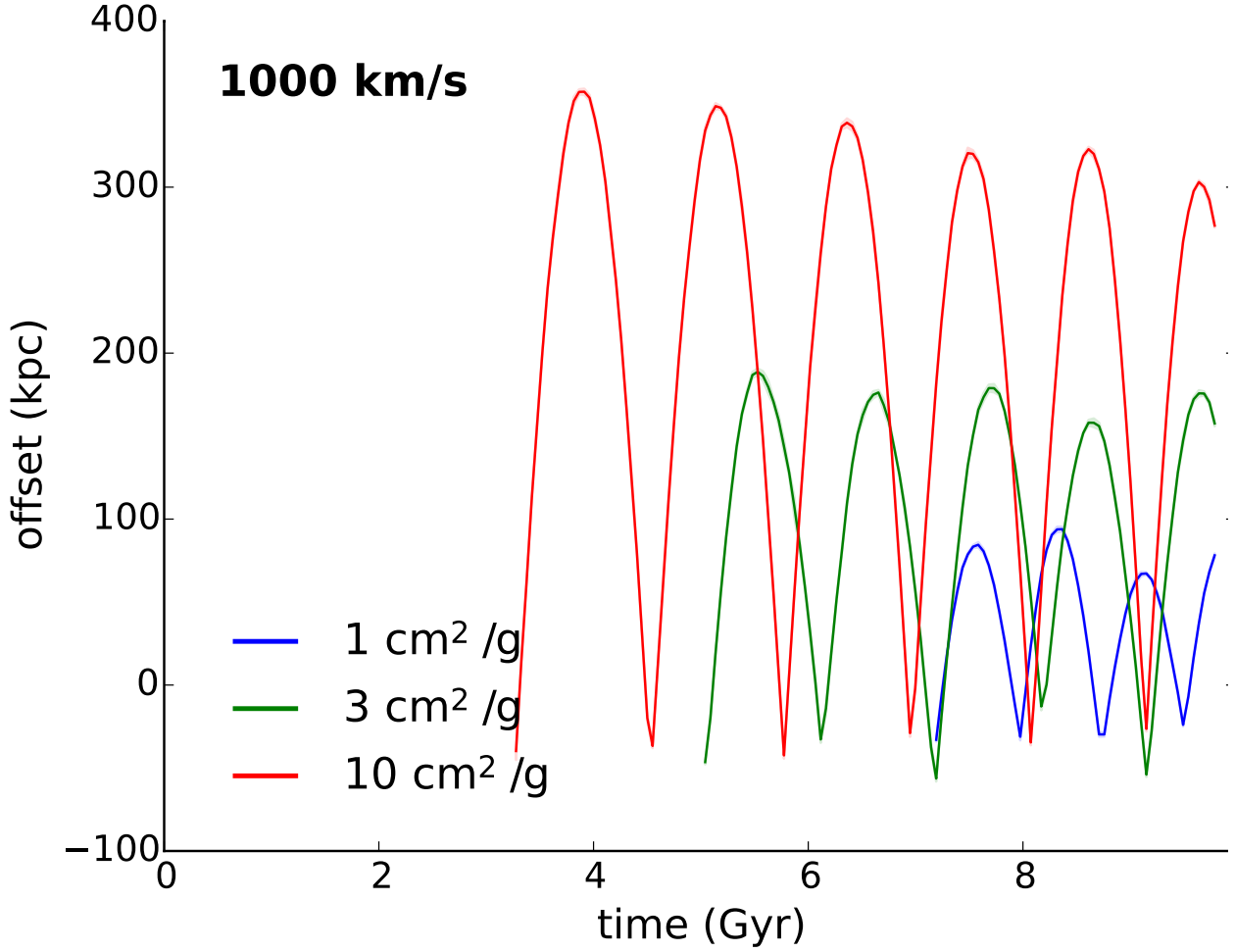


10 cm^2/g: 300 kpc

3 cm^2/g: 200 kpc

1 cm^2/g: 100 kpc

to $\frac{\sigma}{m_\chi}$: alternative constraints?



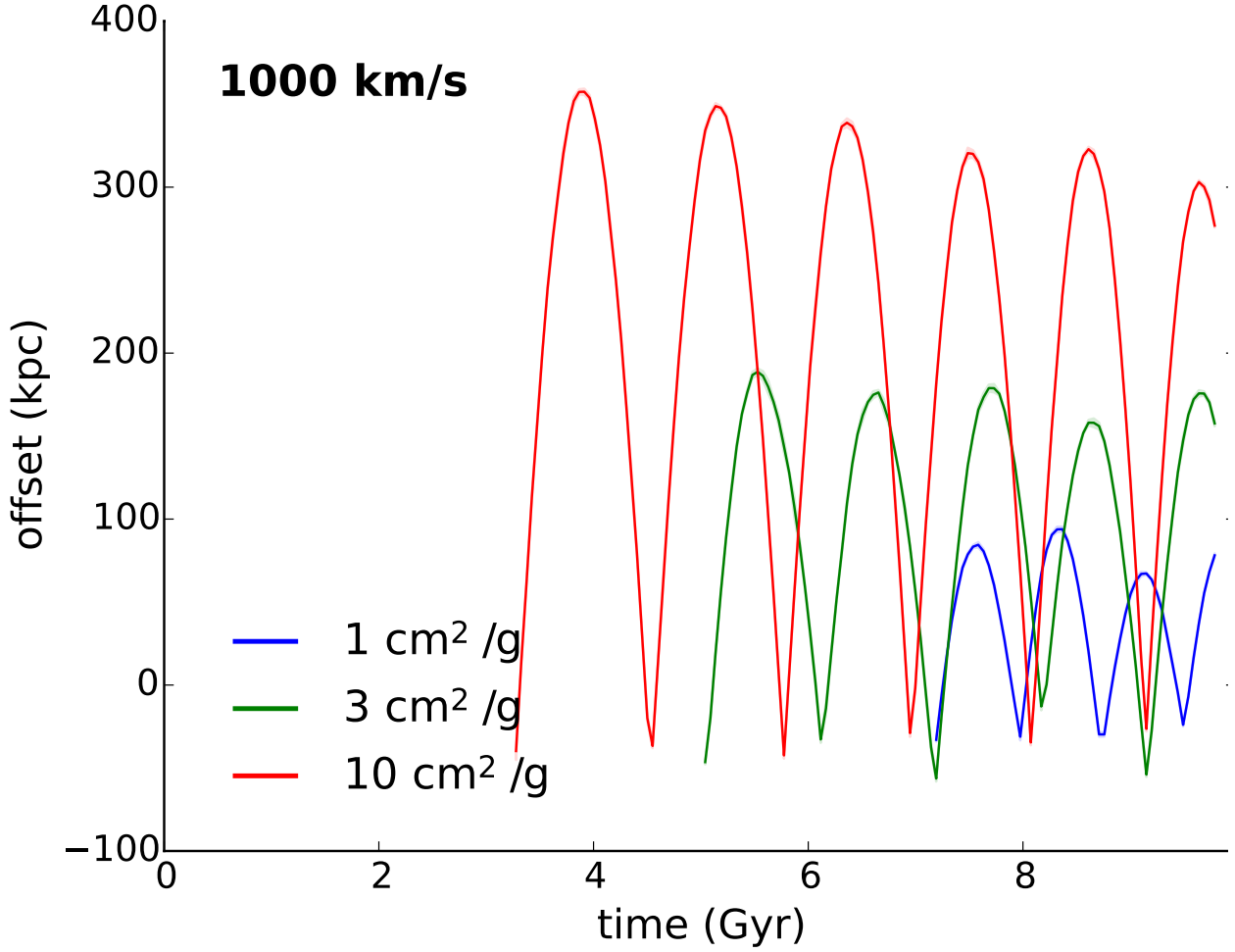
10 cm^2/g: 300 kpc

3 cm^2/g: 200 kpc

1 cm^2/g: 100 kpc

scales with cross section!

to $\frac{\sigma}{m_\chi}$: alternative constraints?



10 cm^2/g: 300 kpc

3 cm^2/g: 200 kpc

1 cm^2/g: 100 kpc

scales with cross section!

observed: 10s of kpc ⟶ $\sigma/m \leq 0.1$ cm^2/g

equal mass mergers: a summary

expected offsets are ≤ 20-50 kpc

(smaller than obs. uncertainties +
too small to explain observed offsets)

alternative methods may
provide better SIDM constraints

(BCG miscentering could give ≤ 0.1 cm^2/g)

EXTRAS

particles from opposite halos interact

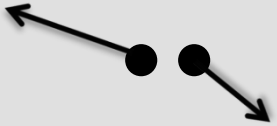
three outcomes

capture

both bound

exchange

one bound



escape

none bound

given **velocity distribution** + **escape velocity,**
can compute likelihood of each outcome

given **velocity distribution** + **escape velocity,**
can compute likelihood of each outcome

particles from opposite halos

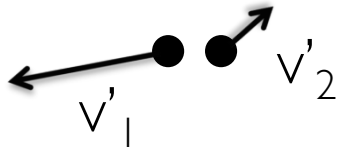
Maxwell-Boltzmann distribution

$$P_{\rm halo1}(v) = P_{\rm MB}(v, \sigma_v)$$

$$P_{\rm halo2}(v) = P_{\rm MB}(v - v_{\rm col}, \sigma_v)$$

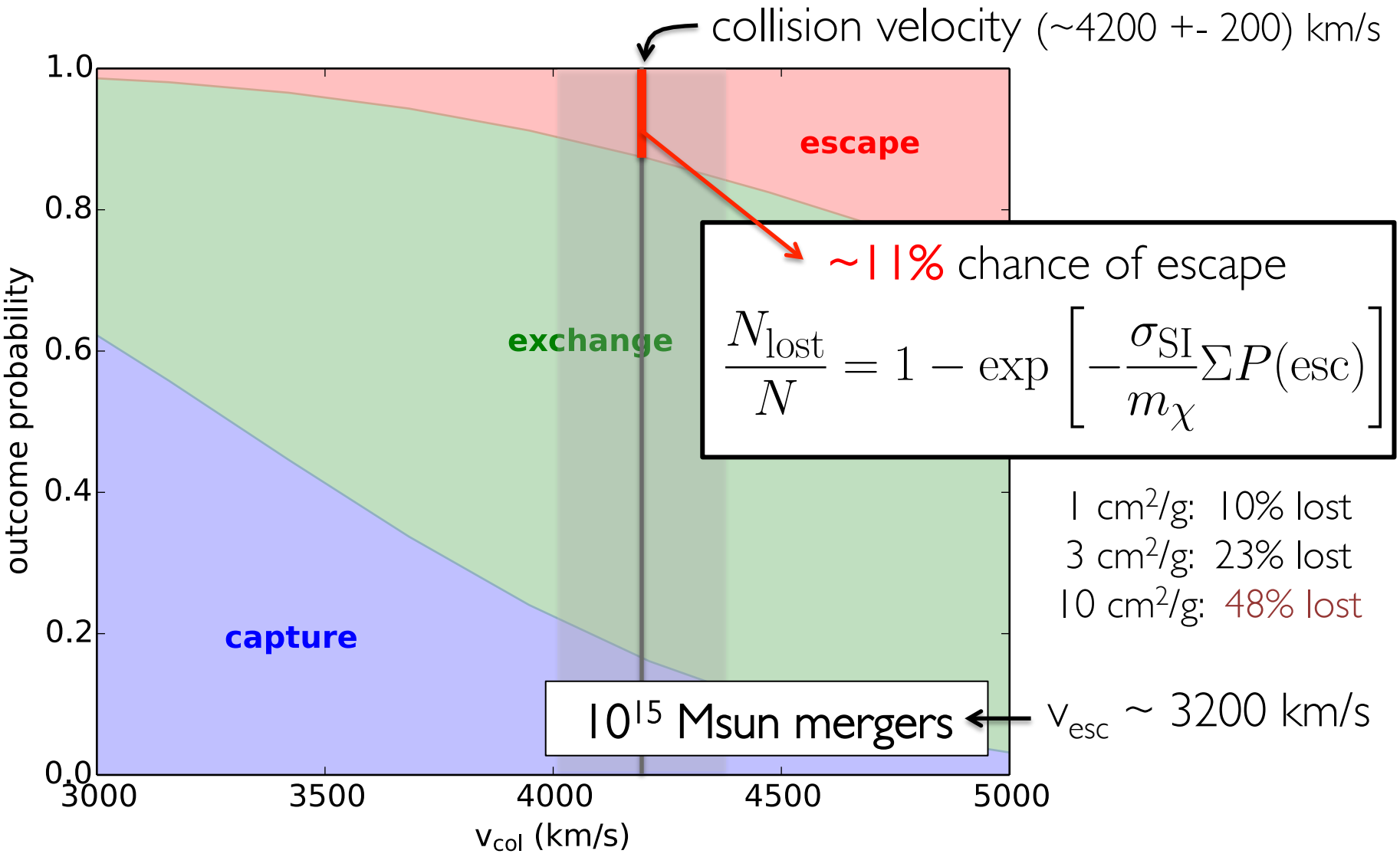
with $\sigma_v = v_{\rm esc}/4$ (for cored profiles)

self-interaction
(isotropic scattering)



escape velocity $v_{\rm esc} \sim \sqrt{\frac{GM}{R}} \sim M^{1/3}$

outcome probabilities



particles from opposite halos interact

three outcomes

capture

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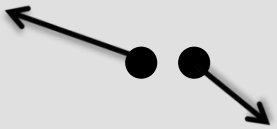


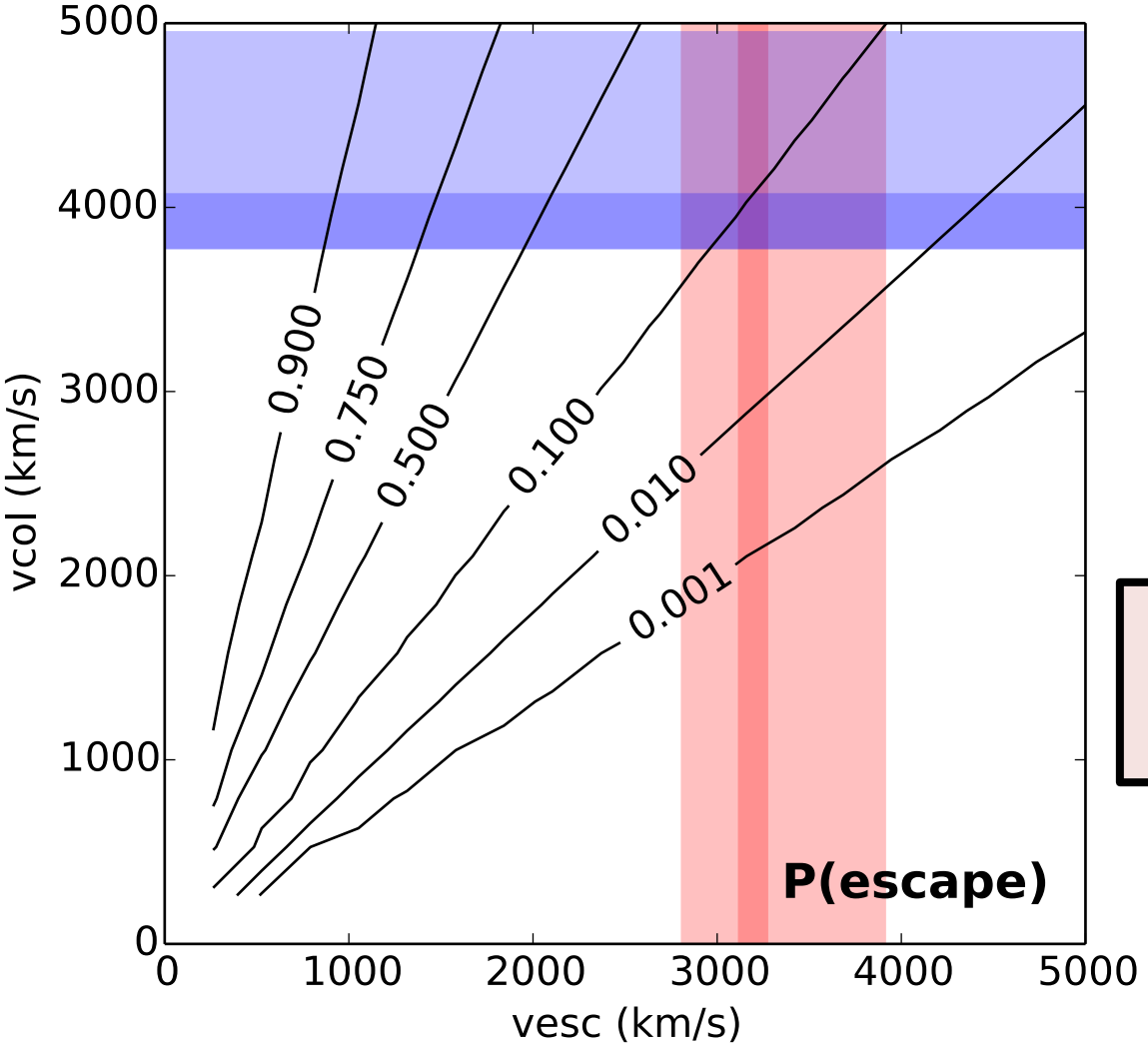
escape

none bound

momentum loss ("drag")

mass loss (tails)

outcome probabilities, more generally



our inputs scale as

$$v_{\rm col} \sim M^{1/3}$$

$$v_{\rm esc} \sim M^{1/3}$$

$$\sigma_v \sim v_{\rm esc} \sim M^{1/3}$$

outcome probabilities same across all masses!

less ejected in smaller M

outcome probabilities, more generally

unequal mass mergers?

let $q = M_1/M_2$. inputs now scale as:

$$v_{\rm col} \sim \sqrt{M_1(1+q^{-1})}$$

$$\sigma_v = \sqrt{\sigma_{v,1}^2 + \sigma_{v,2}^2} = \sigma_{v,1}\sqrt{1+q^{-2/3}}$$

for a 10:1 merger, $v_{\rm col}$, σ_v are 75% smaller; P(esc) = 0.56!

36%, 66%, 93% of lower-mass cluster lost for 1, 3, 10 cm^2/g

much more likely to be ejected and form tails!

SIDM mergers summary

expected offsets are ≤ 20-50 kpc

too small to explain observed offsets

alternative methods may
provide better SIDM constraints

BCG miscentering could give ≤ 0.1 cm^2/g

underlying processes scale with mass

but tails more likely in unequal mass mergers