Edinburgh PPE seminar - 14 May 2021

self-interacting dark matter and mass stripping of cluster galaxies

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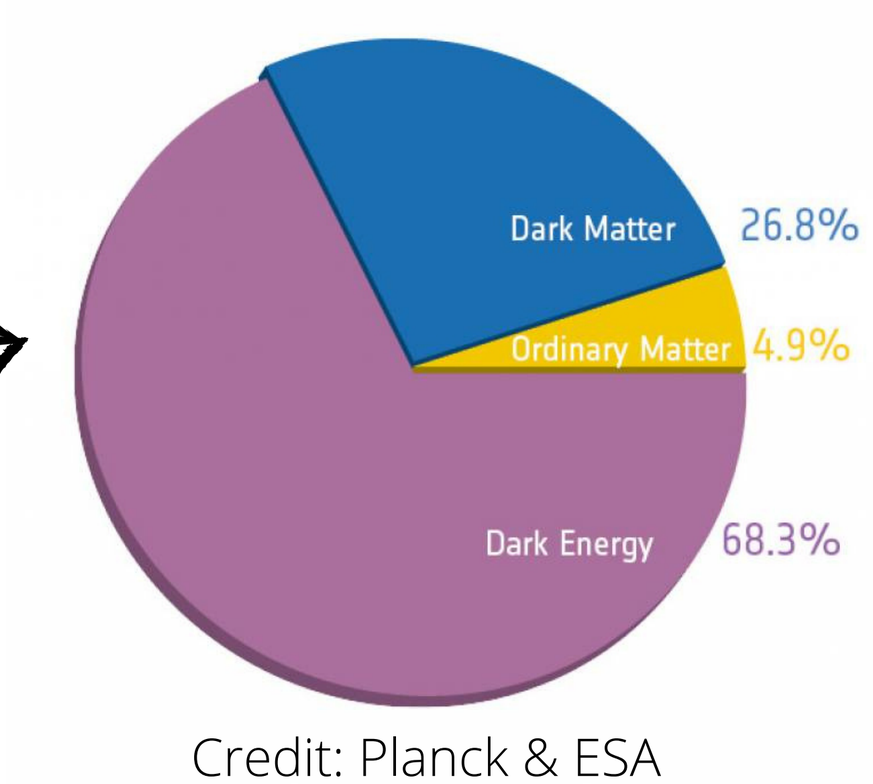
The ΛCDM model

The Standard Model of Cosmology

- Cosmological Constant **Λ**:
  --> Dark Energy
- **Cold** Dark Matter (CDM)
- Ordinary Matter



Credit: Planck & ESA

Structure growth

Hierarchical:

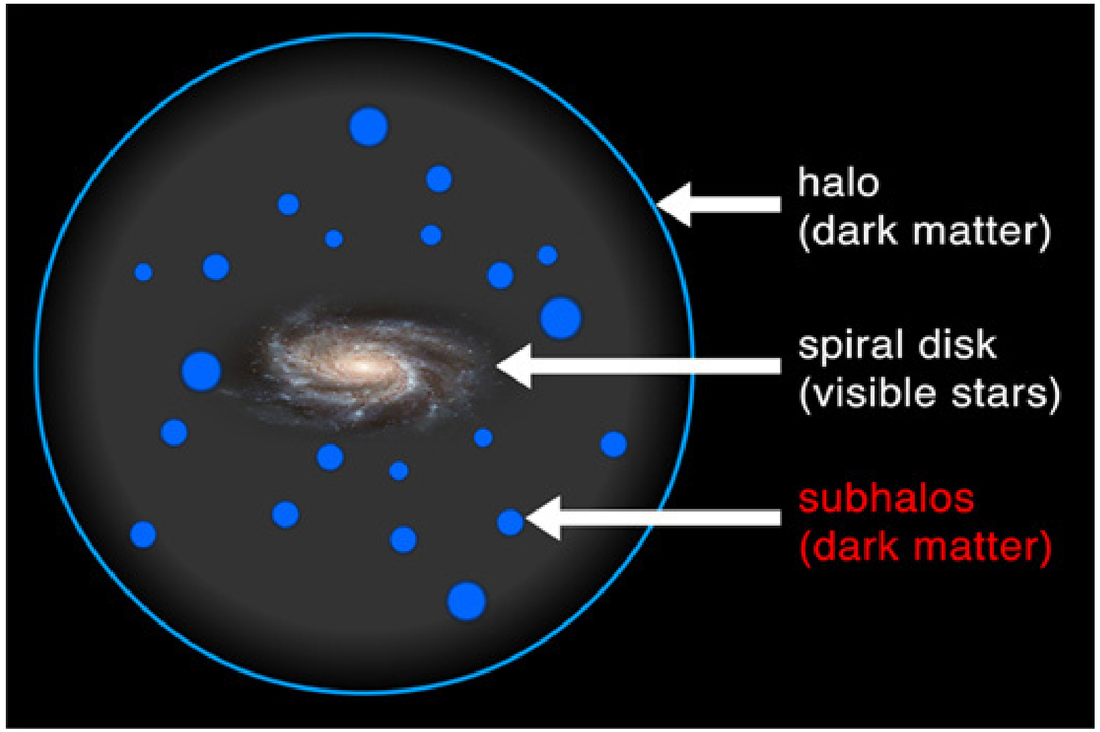
Gravitational evolution

↓

Population of DM haloes

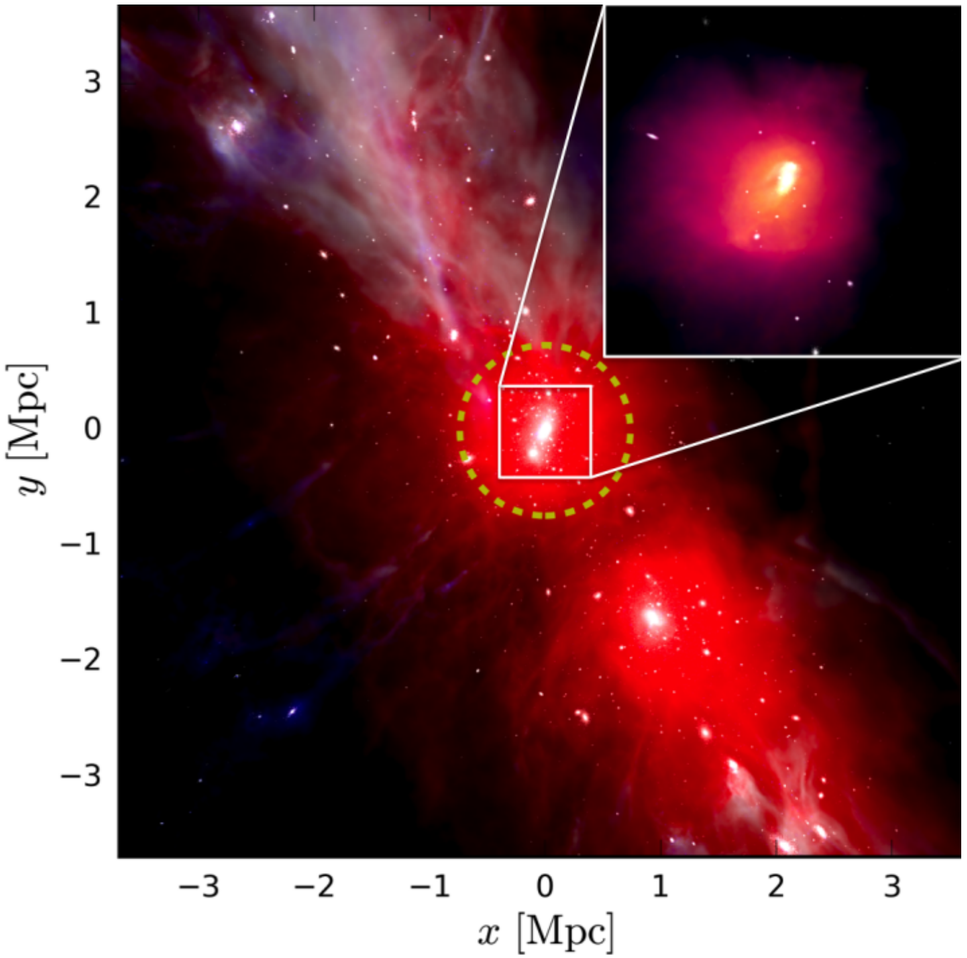
↓

Contain a population of subhaloes



Galaxies form at centres of (sub)haloes

Galaxy clusters



C-EAGLE 5 (z=0.1) - Barnes et al. (2017)

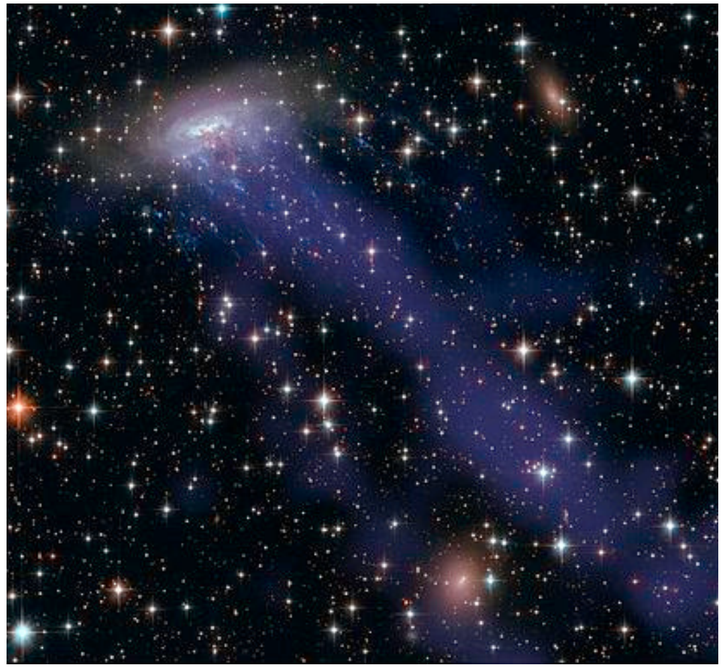
Largest gravitationally bound objects
~100 - 1000 galaxies

↓

In high density environments:
mainly red passive ellipticals

Effects of environment

In clusters:
galaxies subject to violent interactions with environment



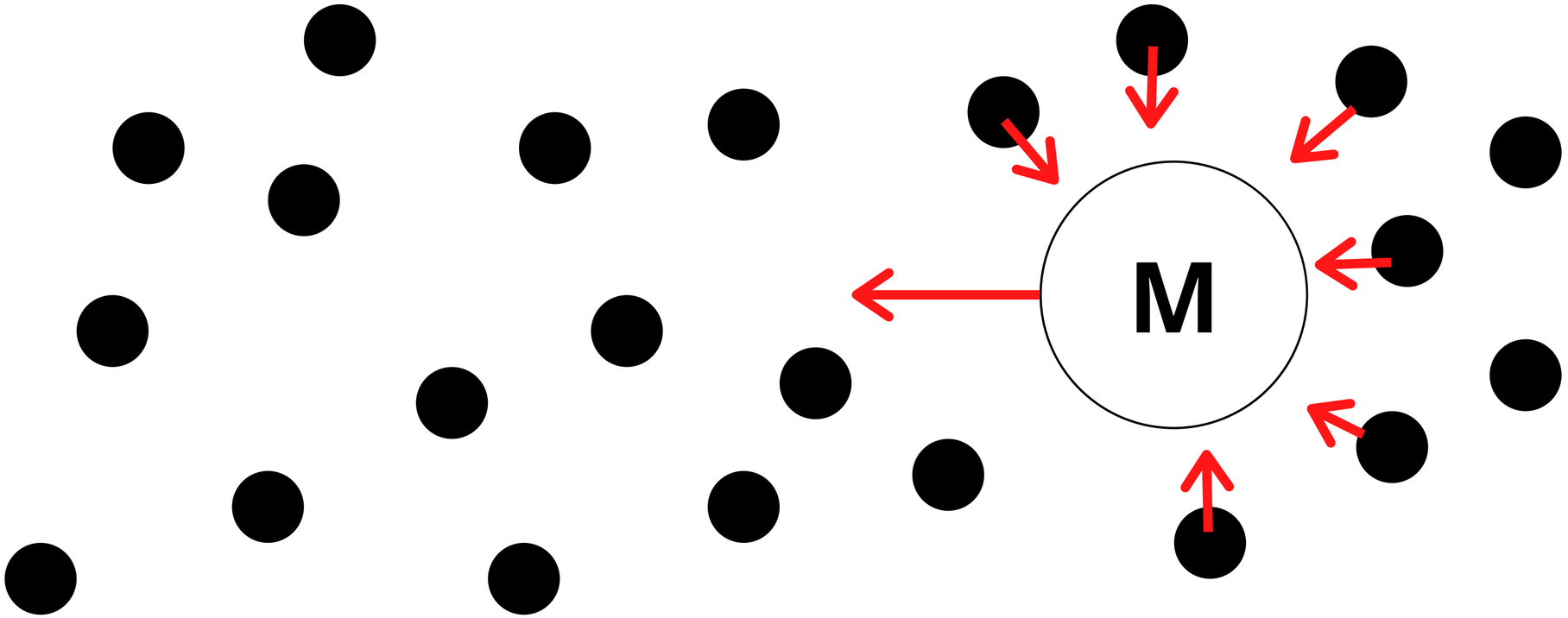
jellyfish galaxy
credit: HST

gas → ram pressure stripping

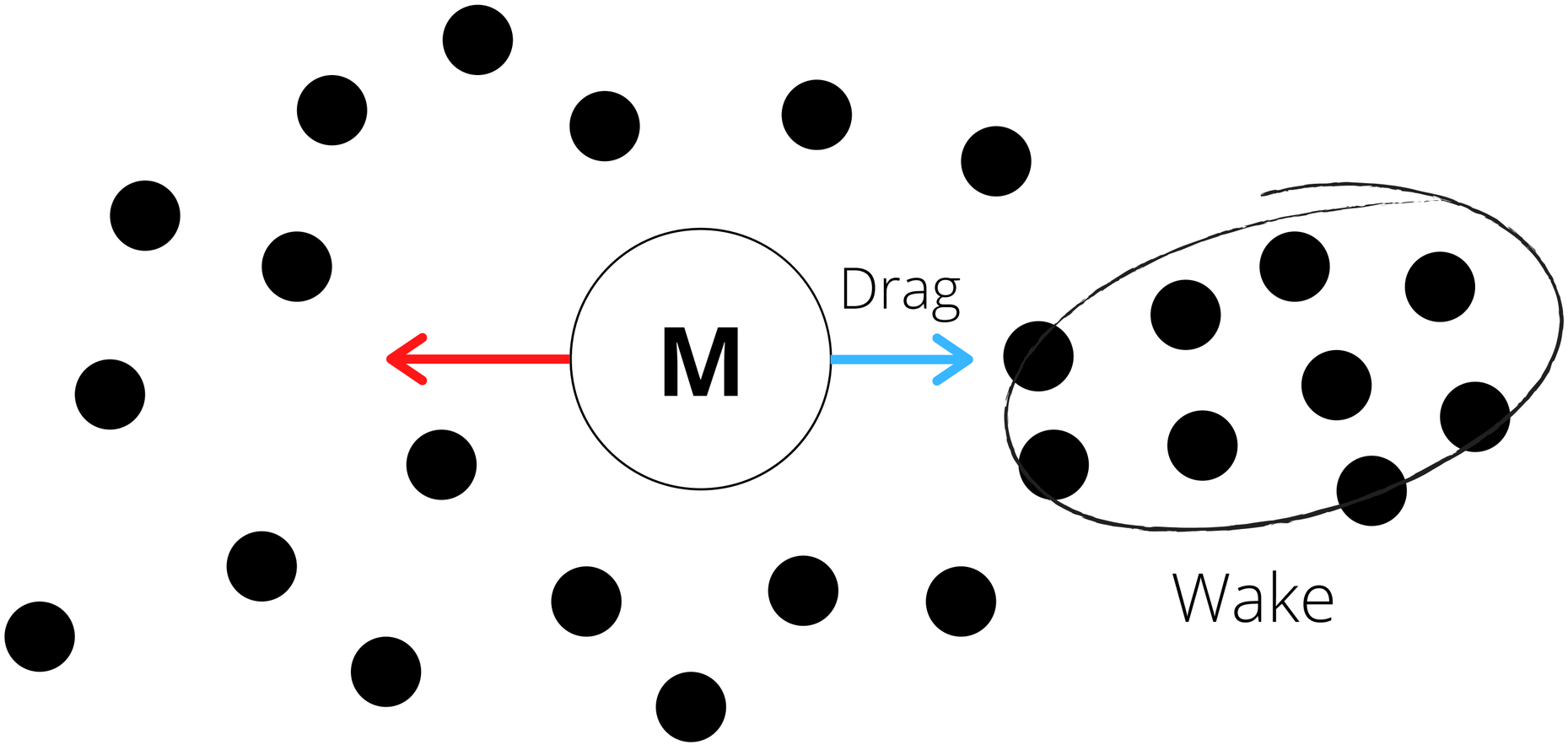
galaxies → harassment & mergers

DM → dynamical friction & **<u>tidal stripping</u>**

Dynamical friction



Dynamical friction

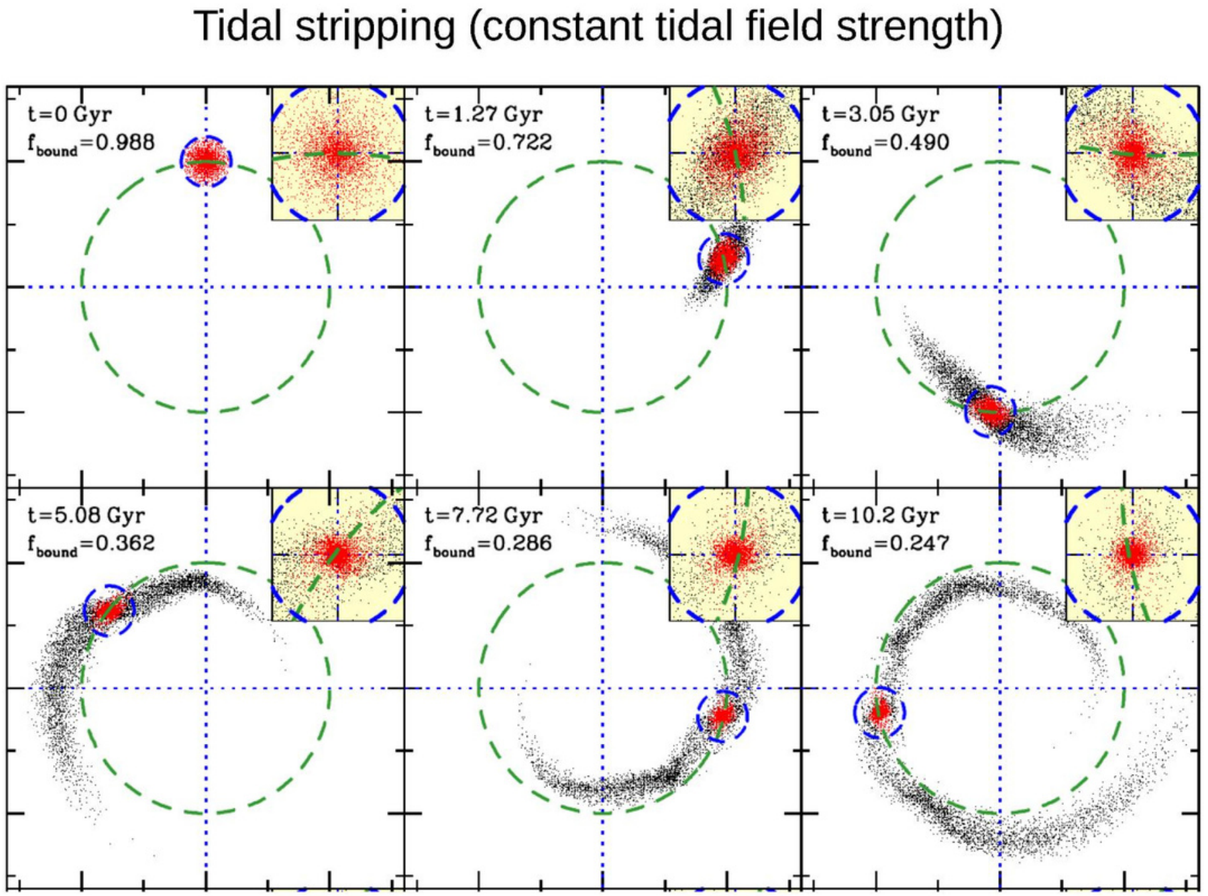


Tidal stripping

Due to strong tidal forces

Scales with galaxy mass cubed & inversely with cluster radius cubed

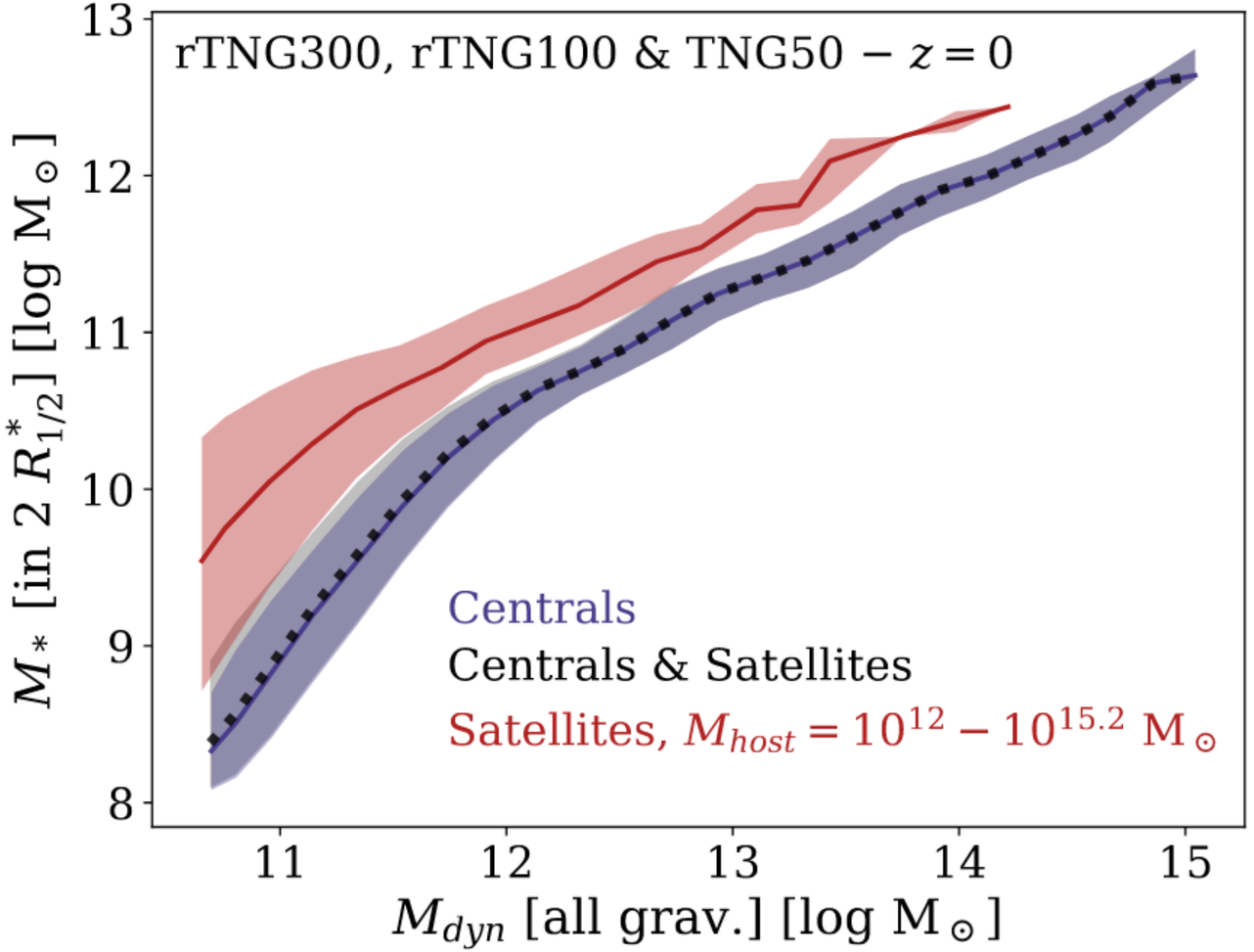
'Outside-in' stripping



Zavala & Frenk (2019)

Tidal stripping

Tidal stripping in ΛCDM simulations

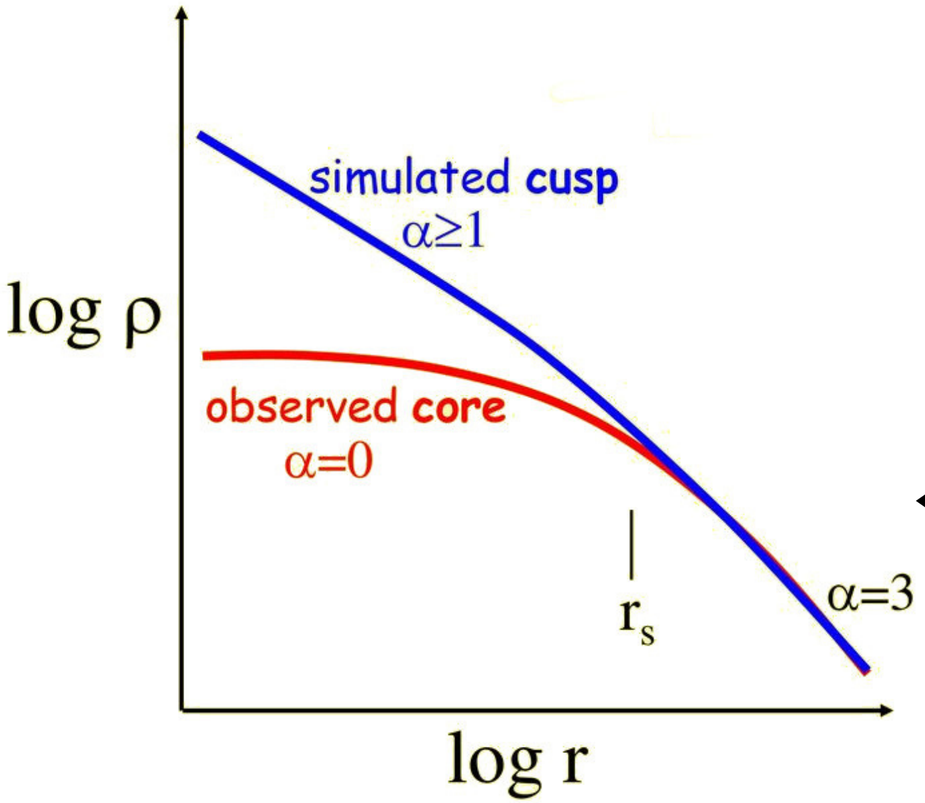


Engler et al. (2020)

Observed as well, e.g. Dvornik et al. (2020)

Discrepancies with CDM

CDM paradigm explains observations on
large scales *O*(Mpc) well



Discrepancies on **subgalactic scales**,
E.g. core/cusp

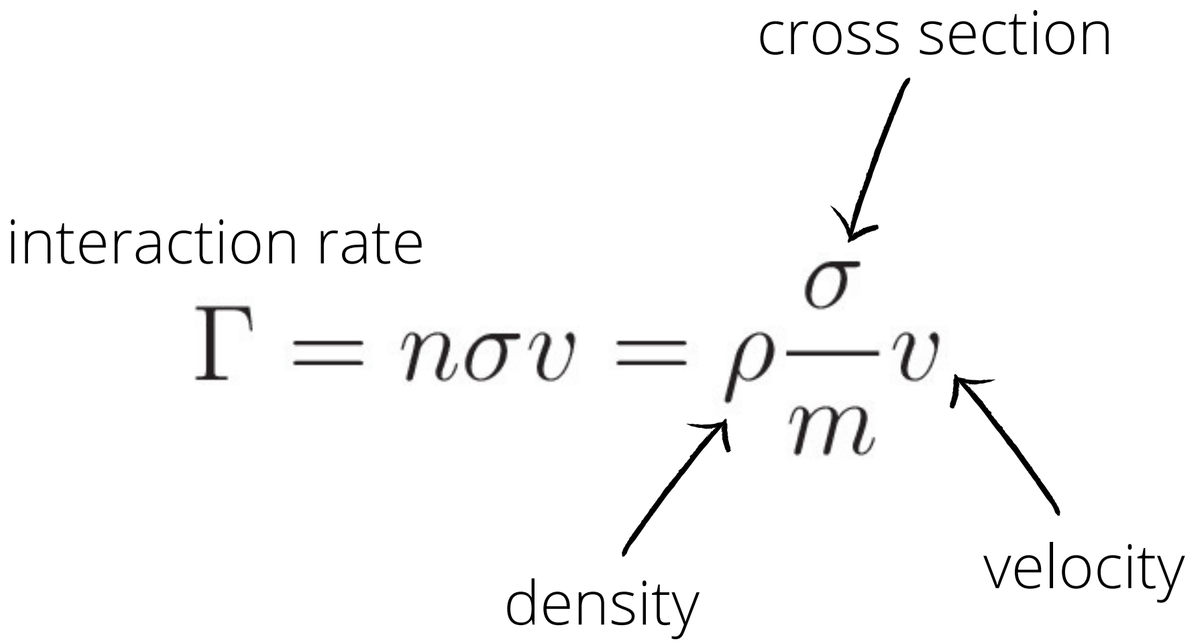
Solutions?

Tension between **DM-only** simulations & observations
--> Include baryons?

--> *Or* not **collisionless**, but **self-interacting** DM (SIDM)?

DM Self-Interactions

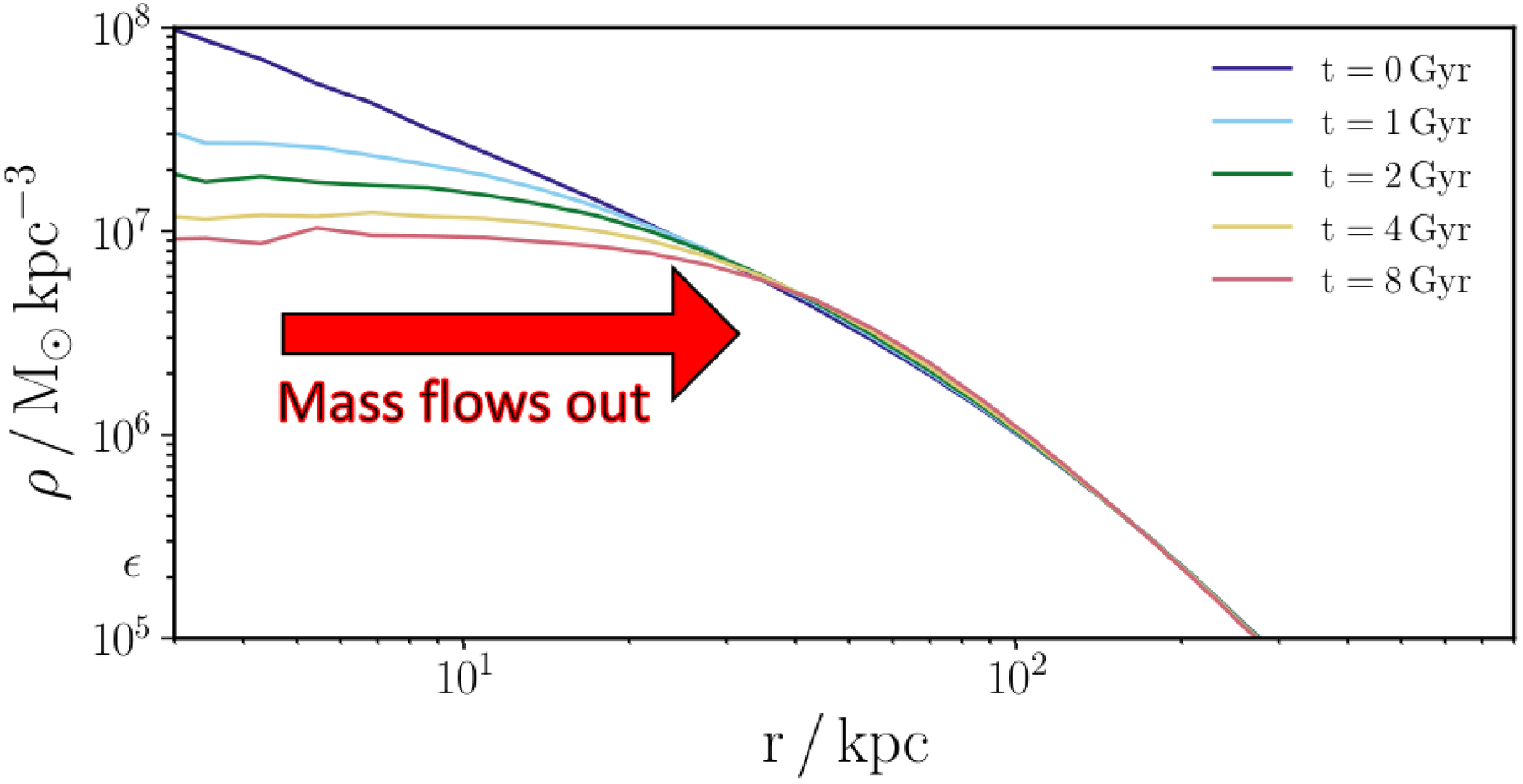
DM particles scatter elastically with each other at astrophysically interesting rates



for 1 interaction per particle per Hubble time:

$$\sigma/m \sim 1\,\mathrm{cm}^2\mathrm{g}^{-1}$$

SIDM can form cores



thermalisation: heated particles --> orbits with larger apocentres

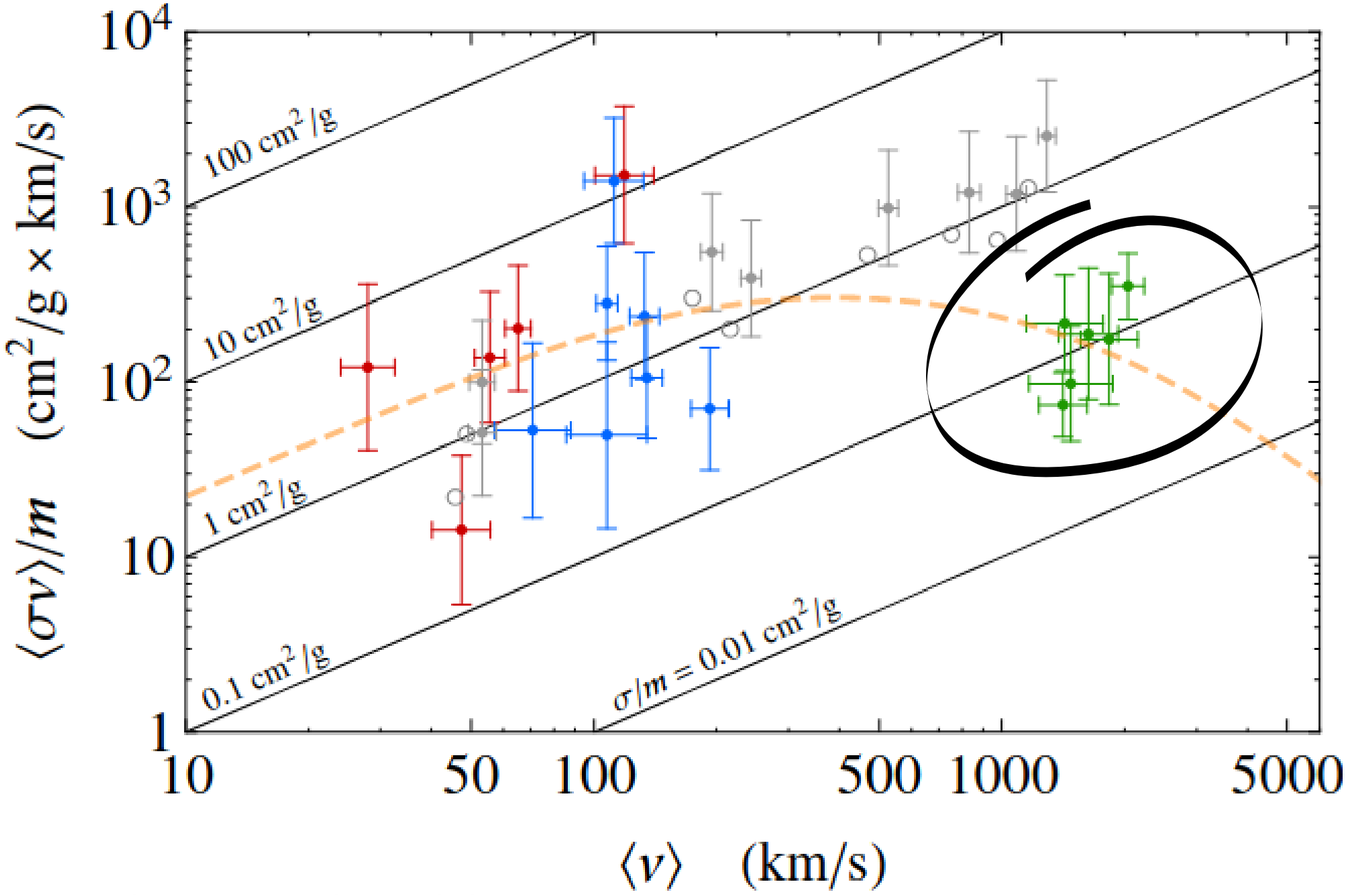
Why look at clusters?

Rates scales with density

+

Local velocity dispersion

Look at massive systems, i.e. **clusters!**

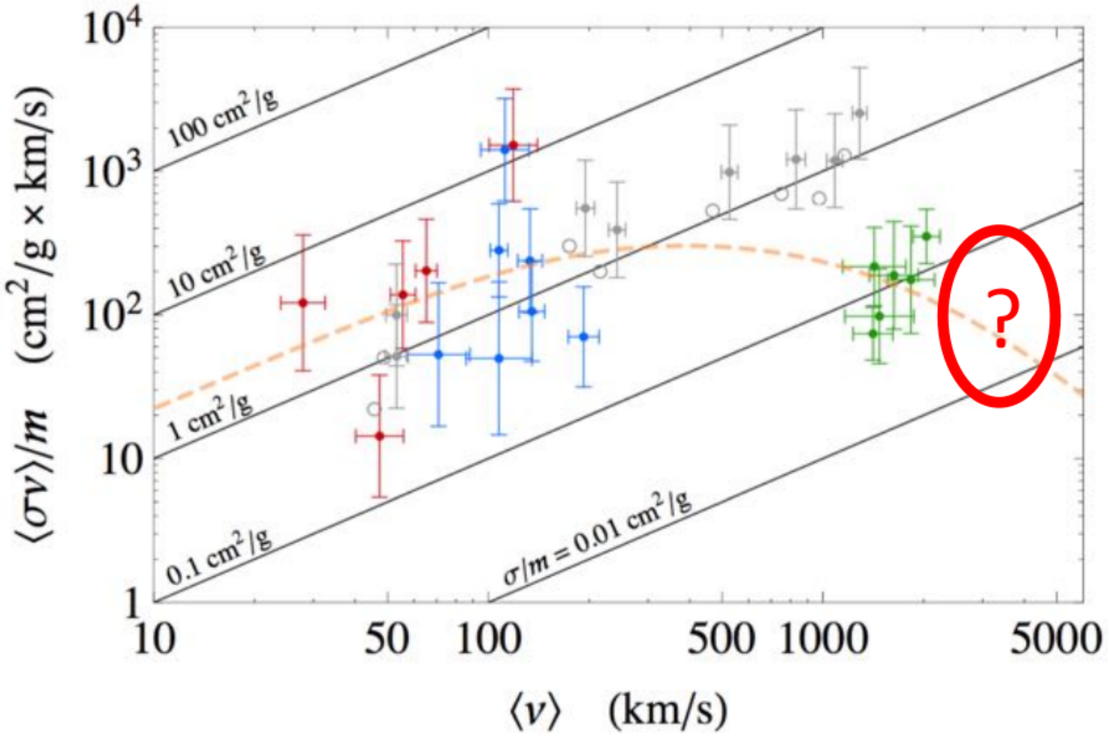


DM distribution can be probed by strong and weak gravitational lensing

Merging clusters

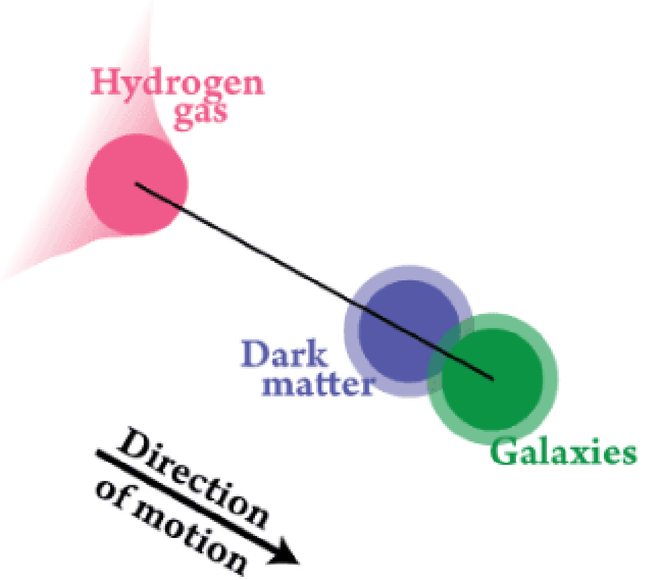
'Cosmic collider'

Higher DM-DM velocities than in isolated galaxy clusters



Dark Matter separated from main baryonic component

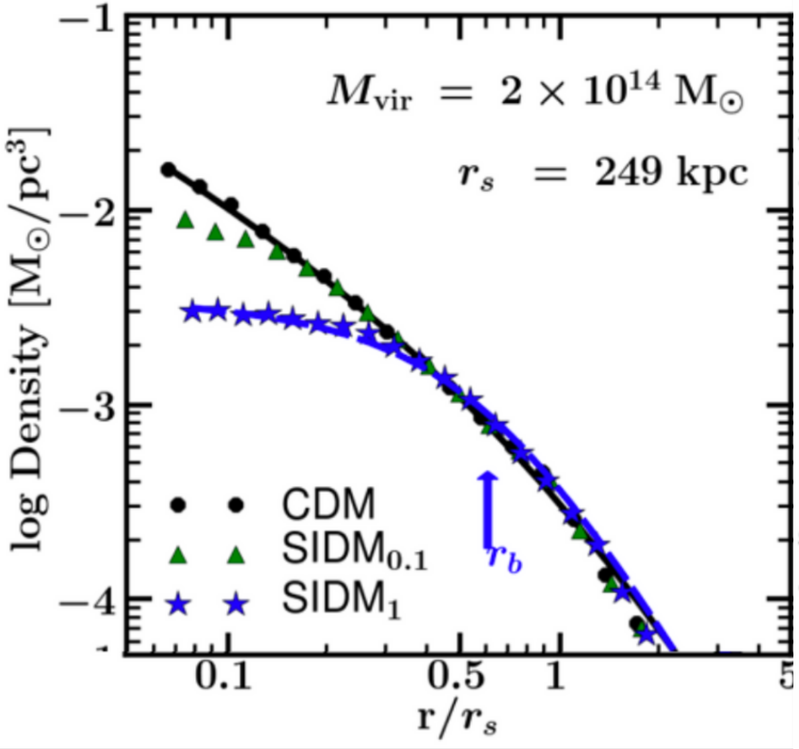
The Bullet cluster simulated



However: small sample, i.e. no statistical analysis

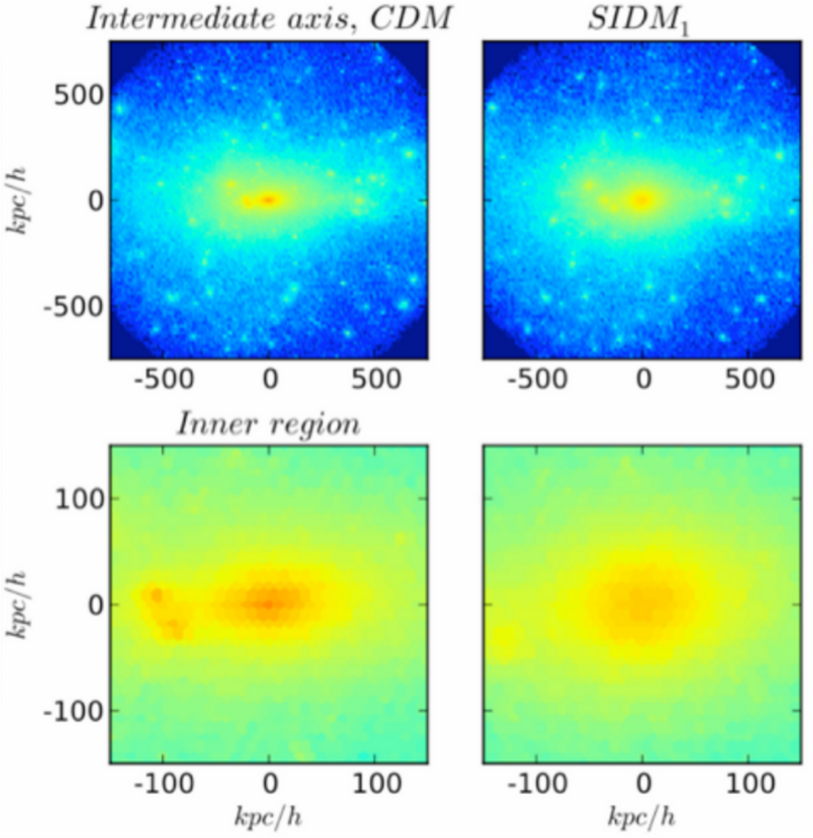
Current cluster constraints

Core sizes:
$\sigma/m < 1\ \mathrm{cm^2 g^{-1}}$



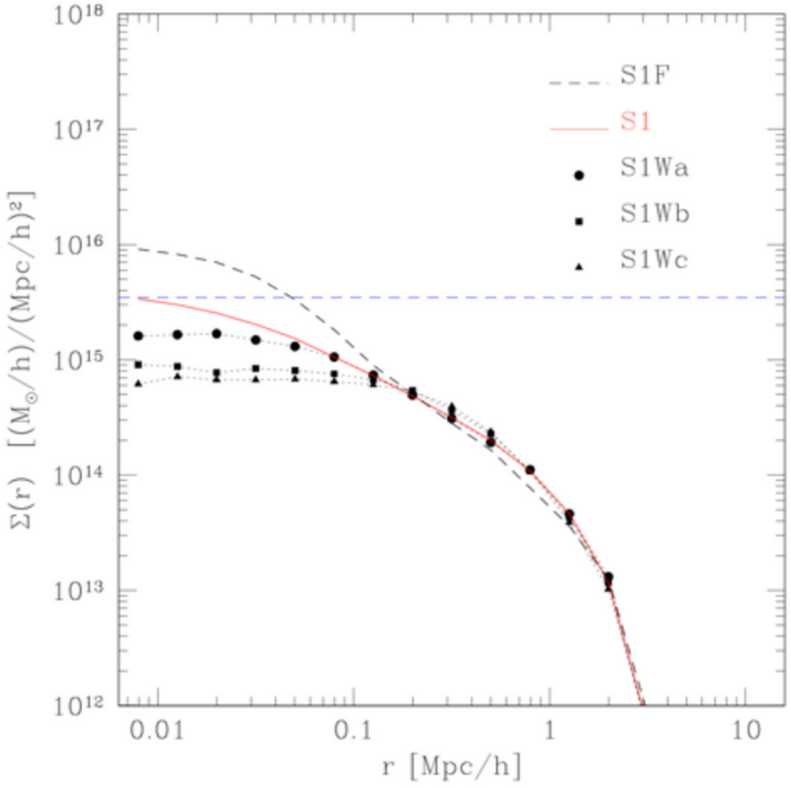
Rocha et al. 2012

Halo shapes:
$\sigma/m \lesssim 1\ \mathrm{cm^2 g^{-1}}$



Peter et al. 2012

Strong lensing:
$\sigma/m < 0.1\ \mathrm{cm^2 g^{-1}}$



Meneghetti et al. 2000

Subhalo evaporation

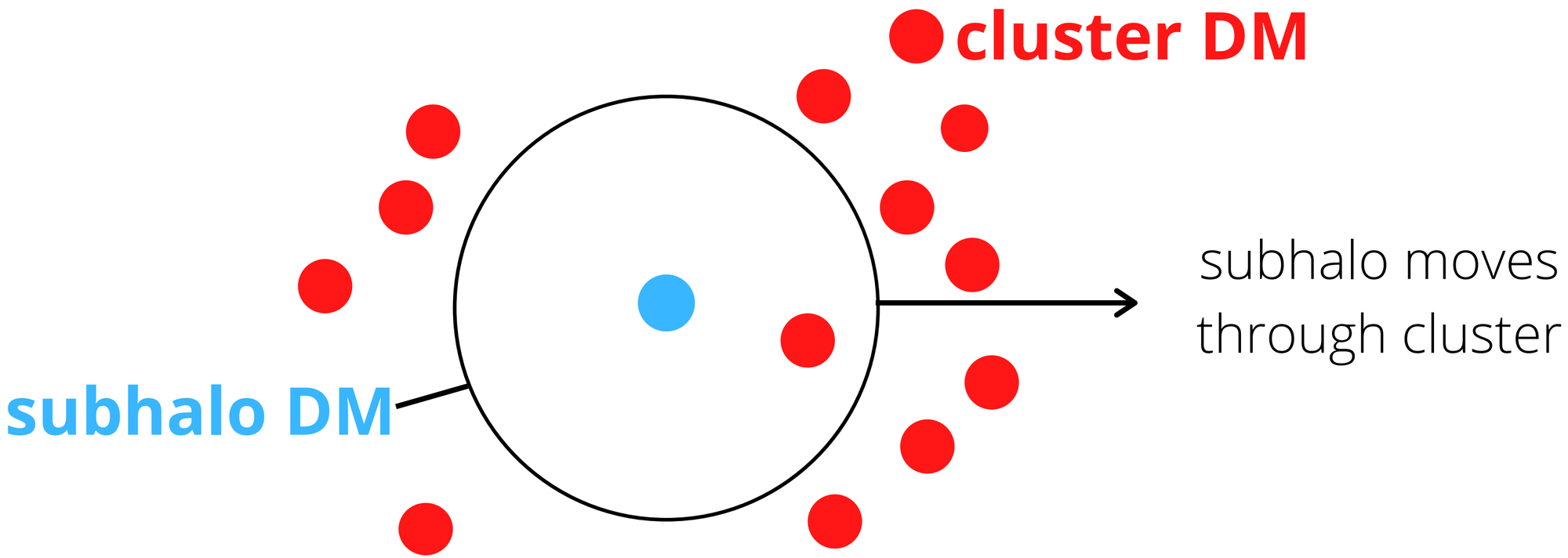
In SIDM: same environmental effects as with CDM

However: additional interactions between galaxy (subhalo) DM and cluster DM

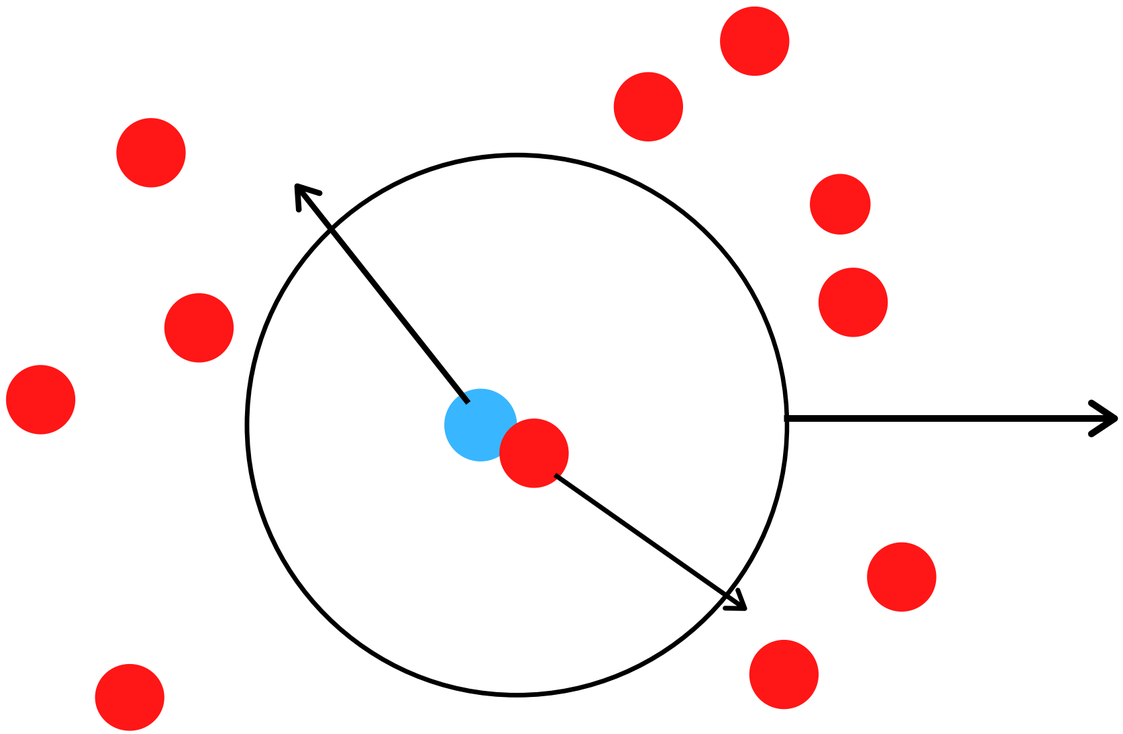
Subhalo DM is scattered out by cluster DM

evaporation

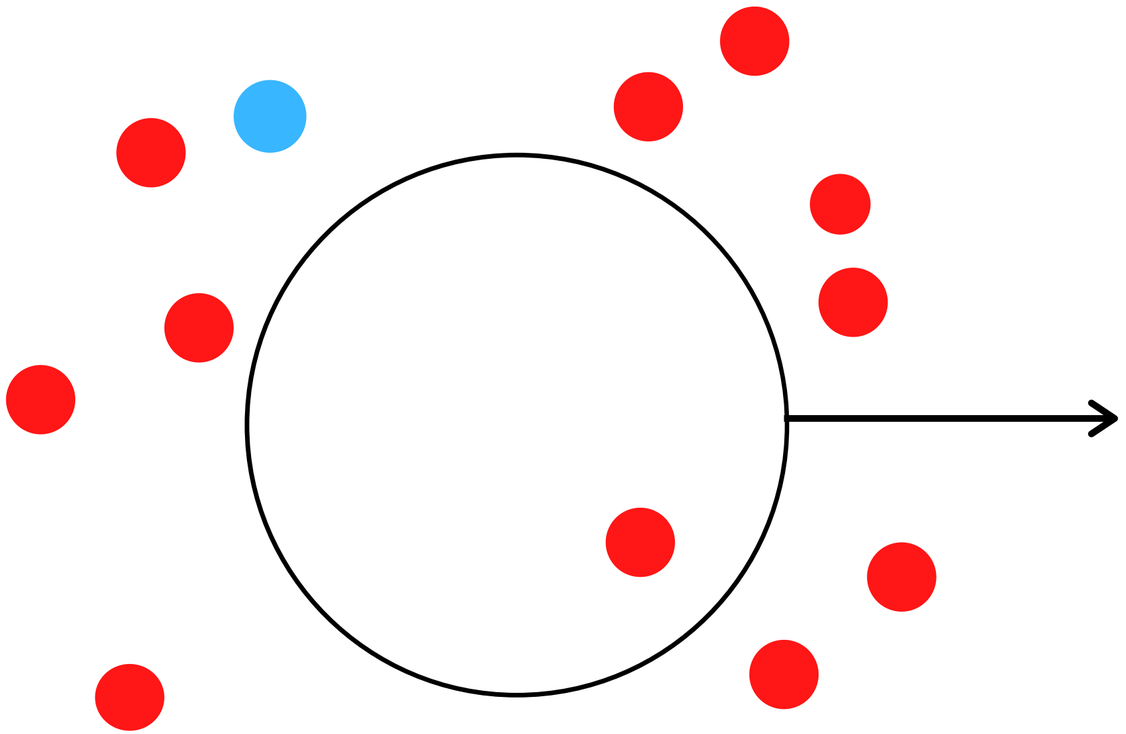
Subhalo evaporation



Subhalo evaporation



Subhalo evaporation



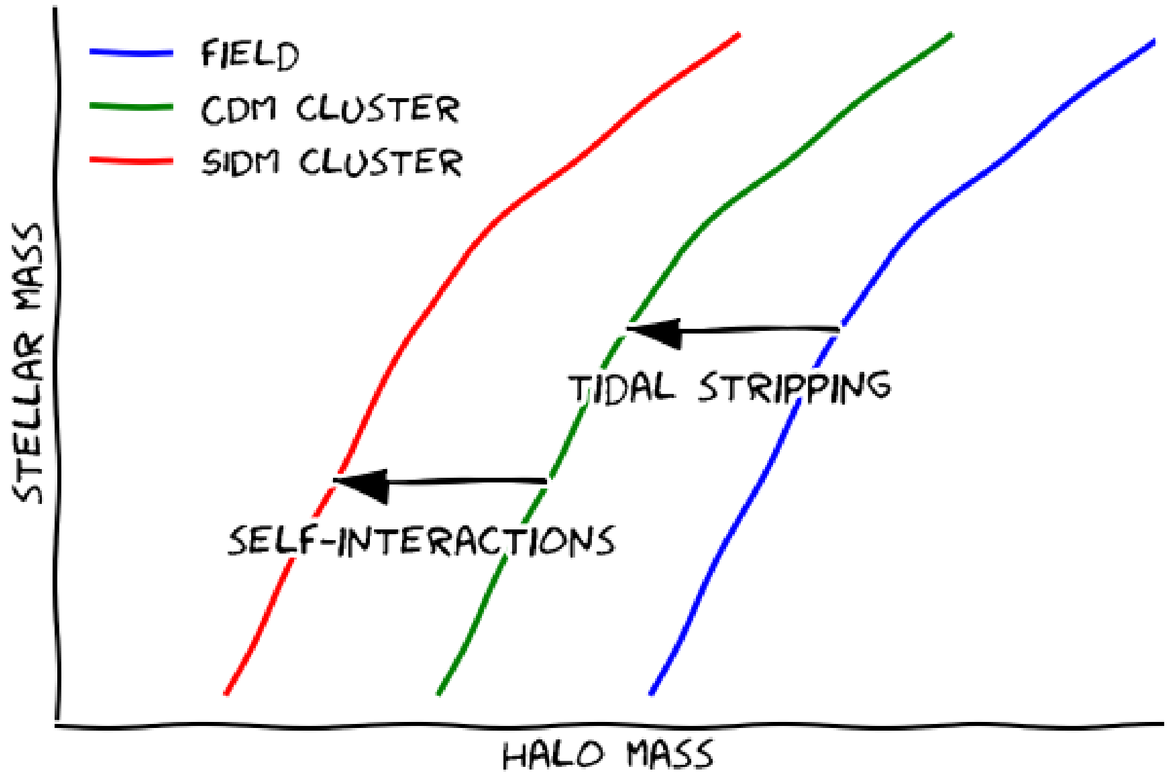
Effects on the Stellar-to-Halo-Mass-Relation

<u>In SIDM cluster:</u>

Enhanced DM loss,
but stellar mass similar
--> SHMR higher?

<u>Outside cluster:</u>

No difference between
CDM & SIDM



This Project

Compare DM loss of subhaloes
in CDM & SIDM cosmological simulations

Is there a clear difference?

Is it observable?

Simulations

C-EAGLE (CE)
Two clusters run
with CDM & SIDM

→ galaxies in clusters

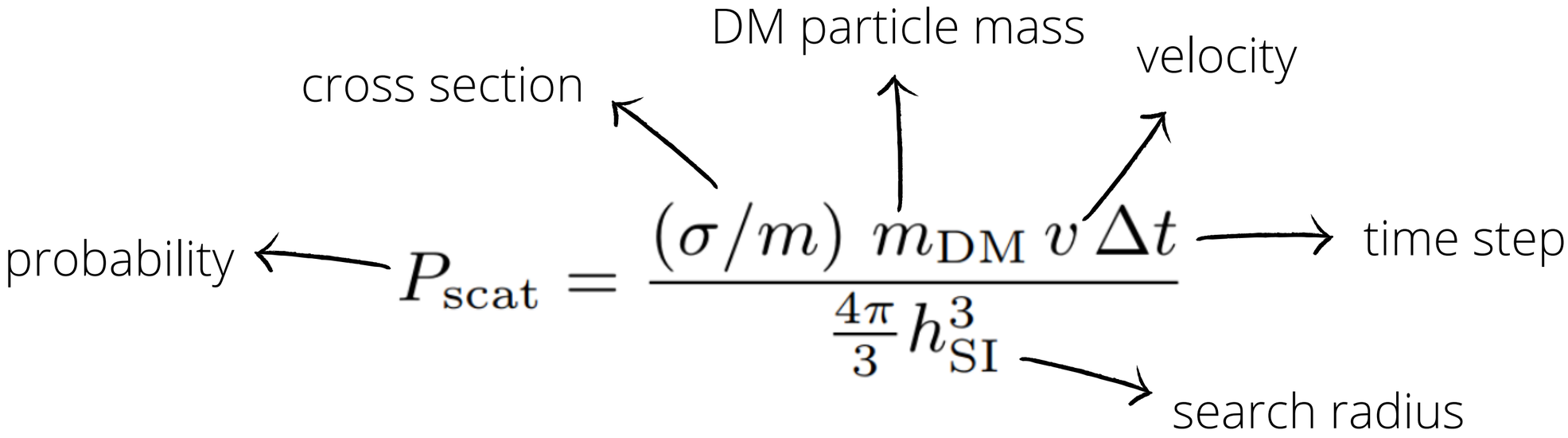
EAGLE (E) 50 Mpc Box
Also run with CDM & SIDM

→ galaxies outside clusters

Implementation of self-interactions

<u>At each time-step:</u>

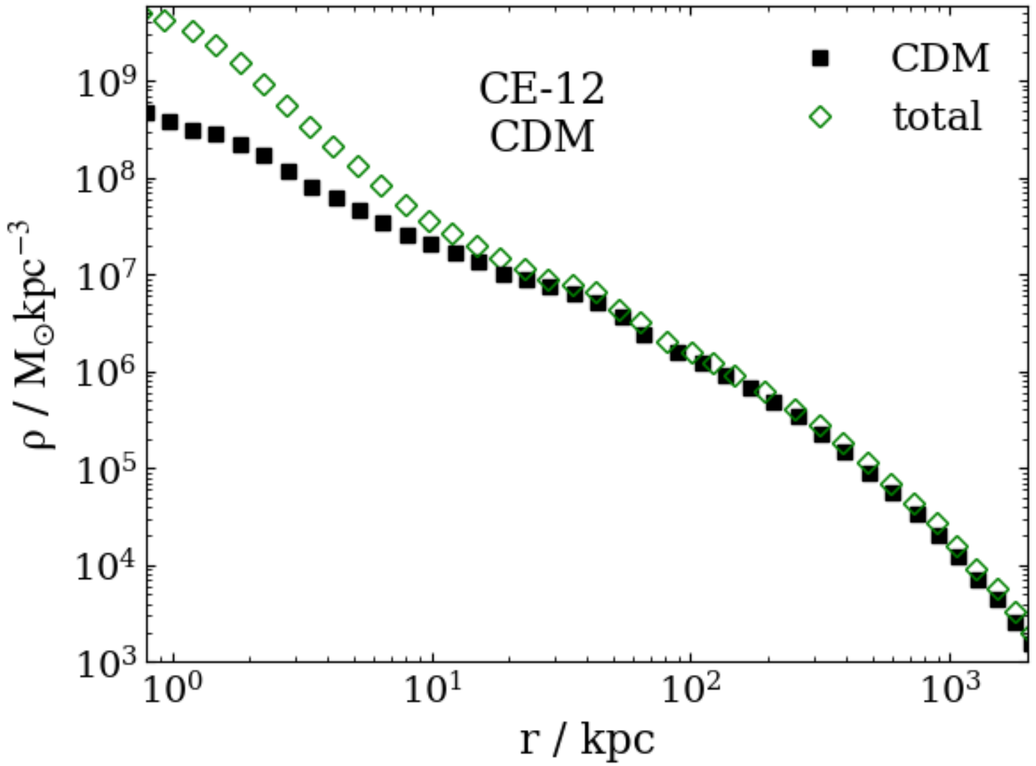
- DM particles search for neighbours within a radius hSI
- Scatter isotropically with probability:

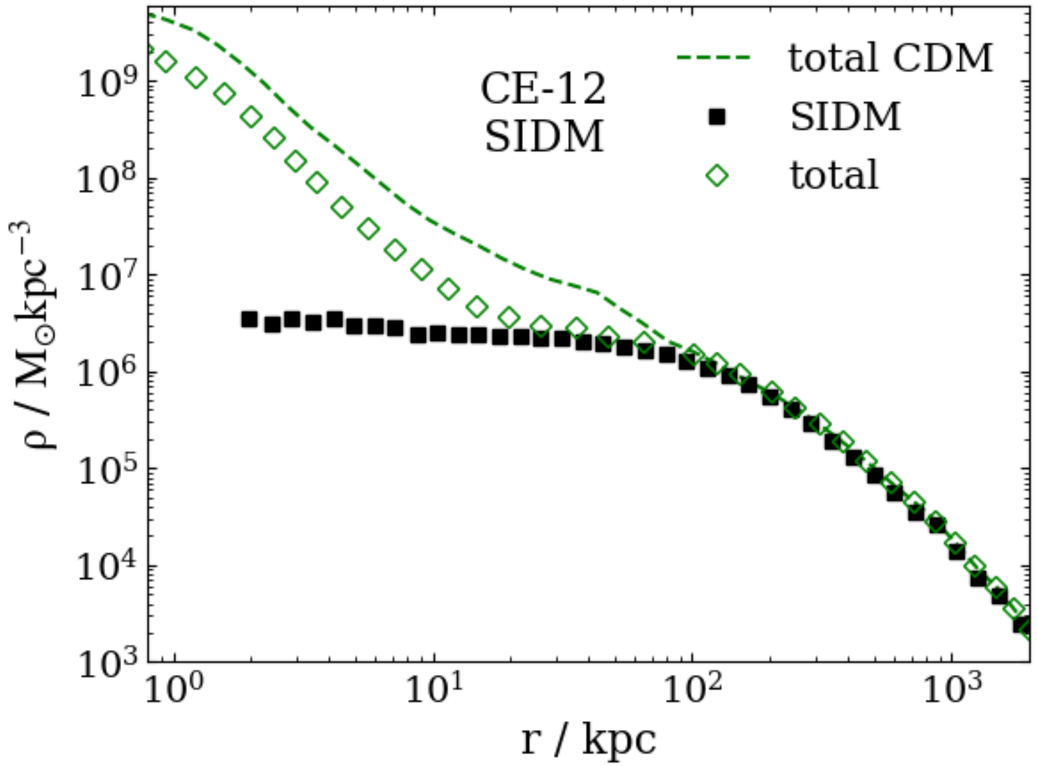


Cross section

$\sigma/\mathrm{m} = 1\ \mathrm{cm}^2/\mathrm{g}$ - 'foot ball'

~Order limit constrained by bullet cluster





Adapted from Robertson et al. (2018)

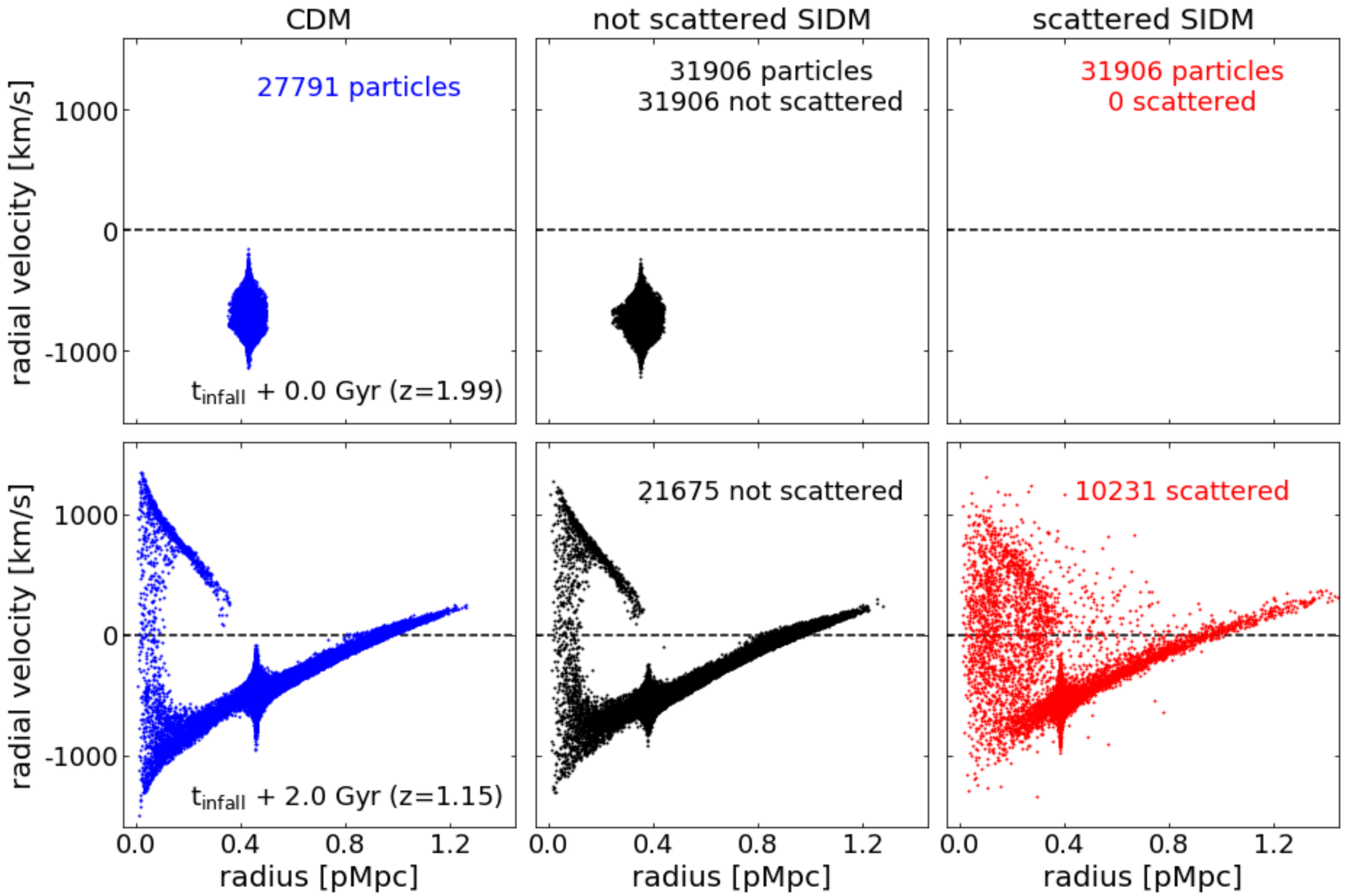
Phase space evolution

In simulations:

Can follow individual particles

+

Follow evolution of properties from infall to later time



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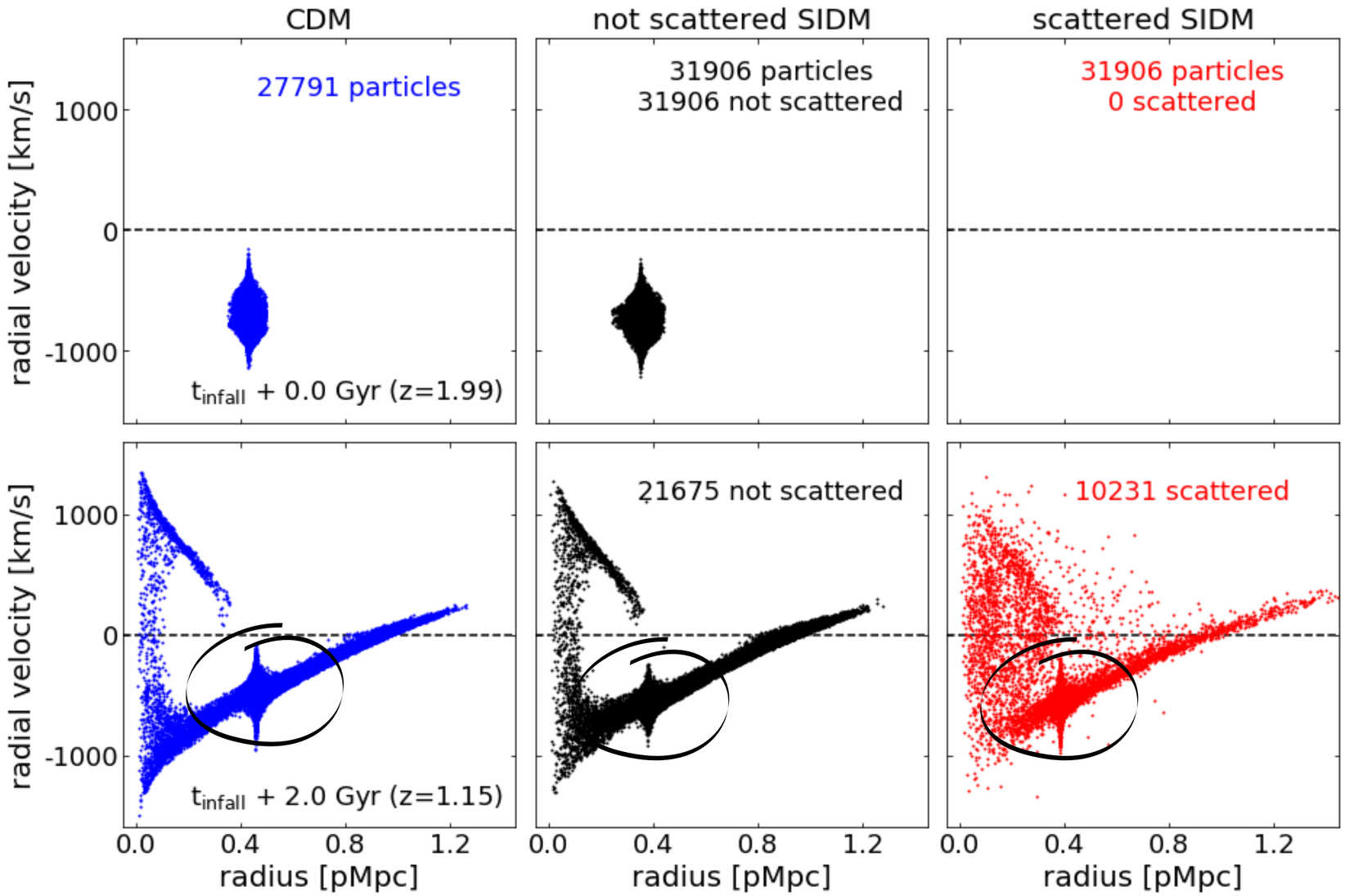

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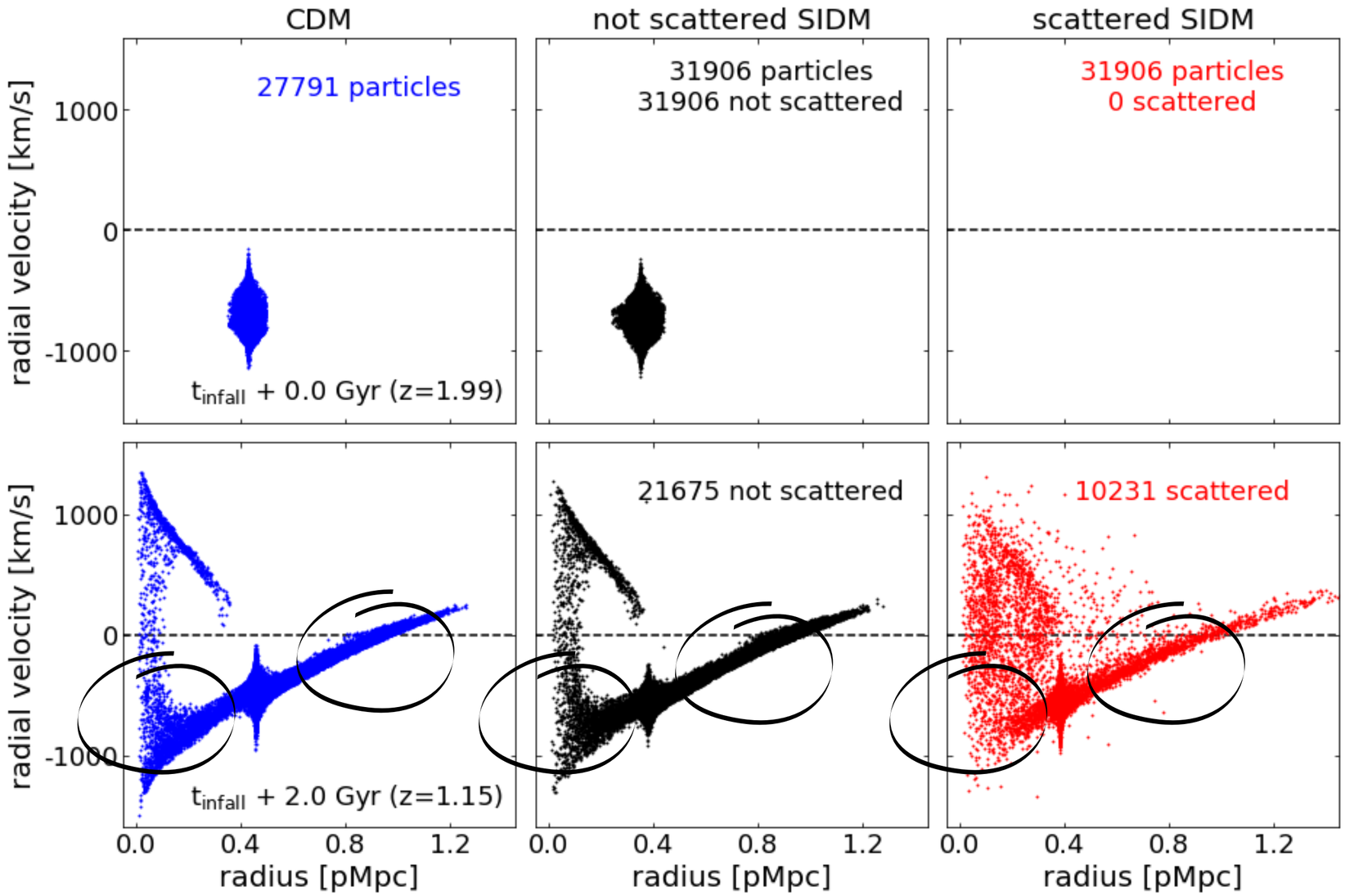

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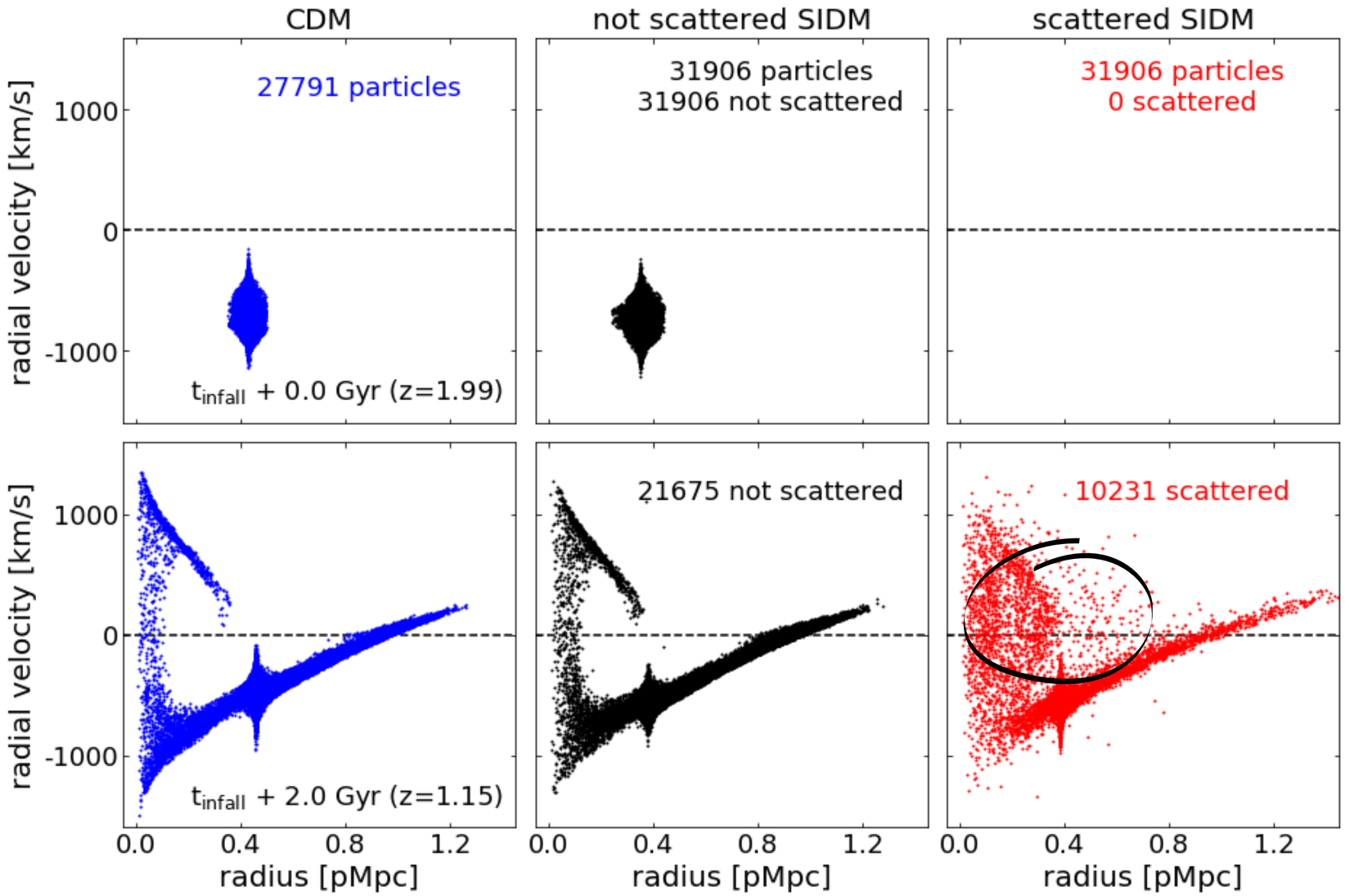
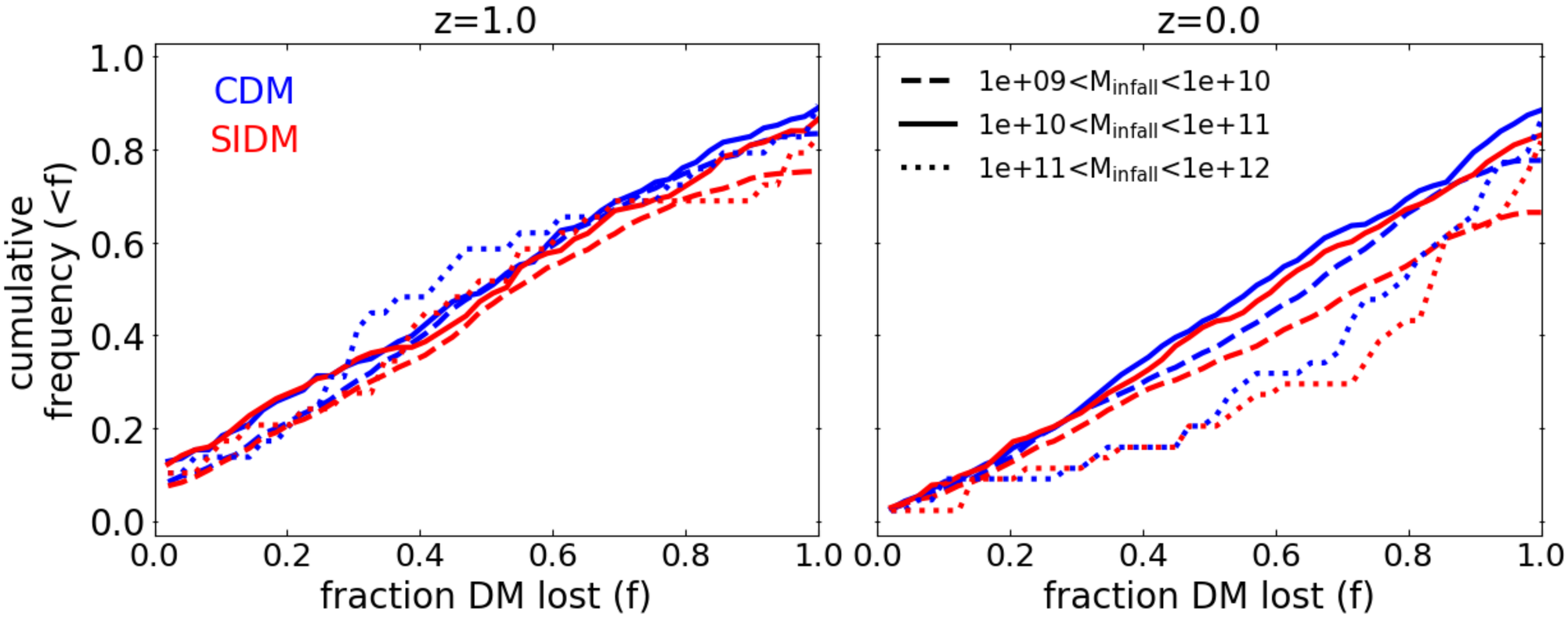
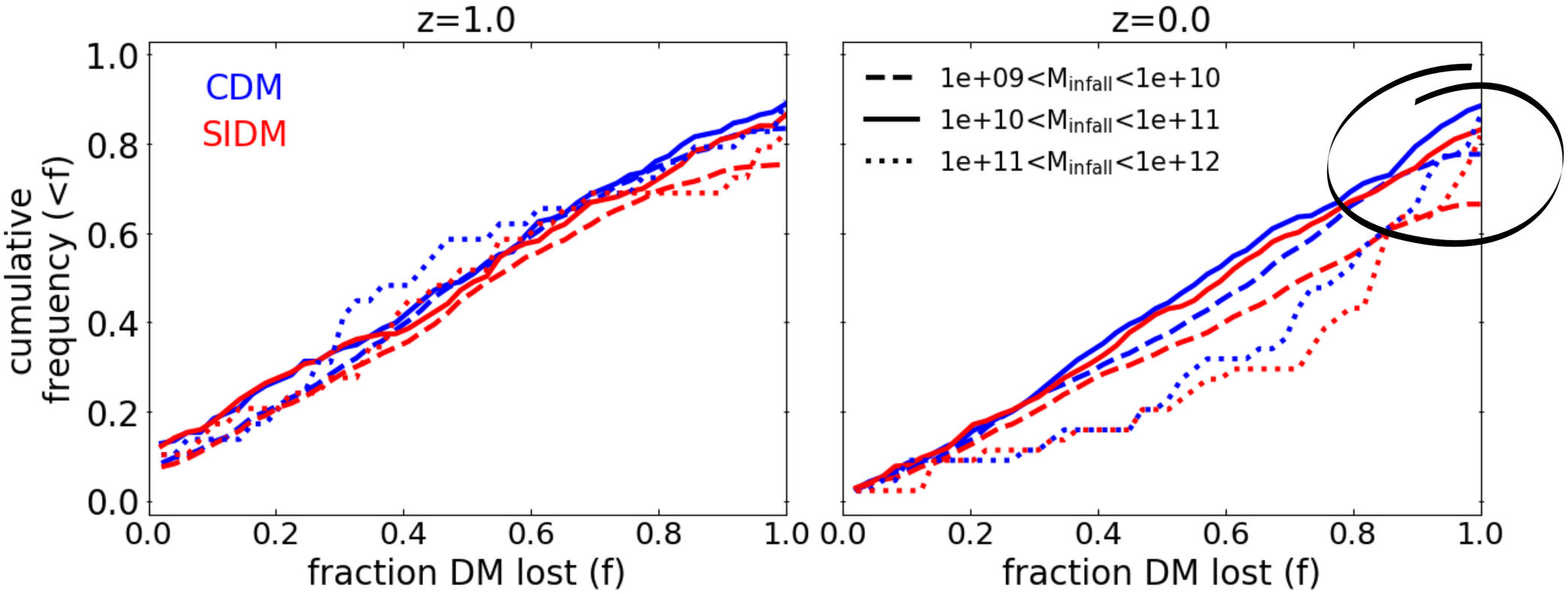


Distribution of mass loss



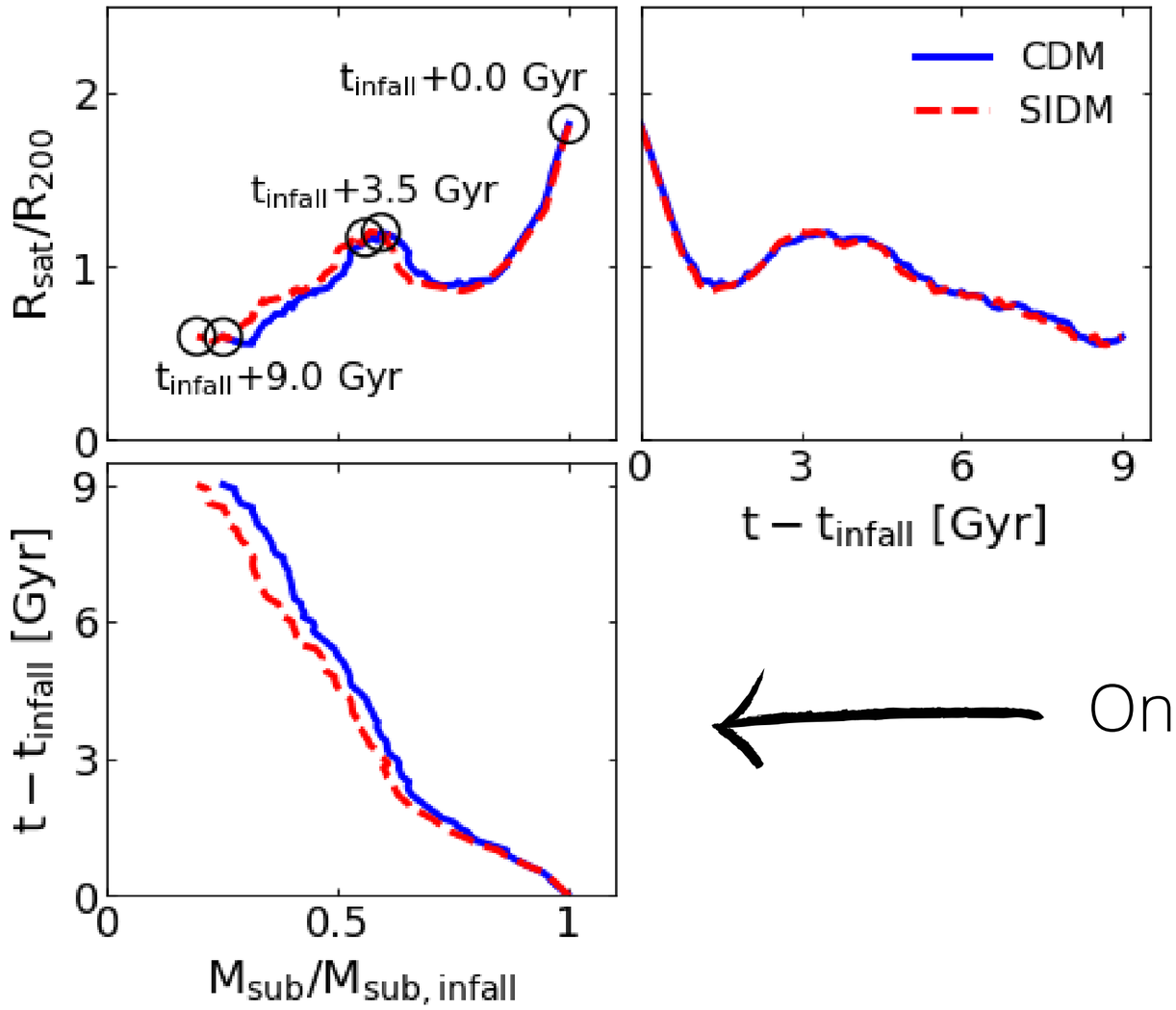
- More SIDM galaxies have disrupted
- SIDM satellites have lost more mass by z=0

Distribution of mass loss



- More SIDM galaxies have disrupted
- SIDM satellites have lost more mass by z=0

Orbits unaffected by SIDM



On average, orbits the same

Only mass loss affected

Effects of SIDM observable?

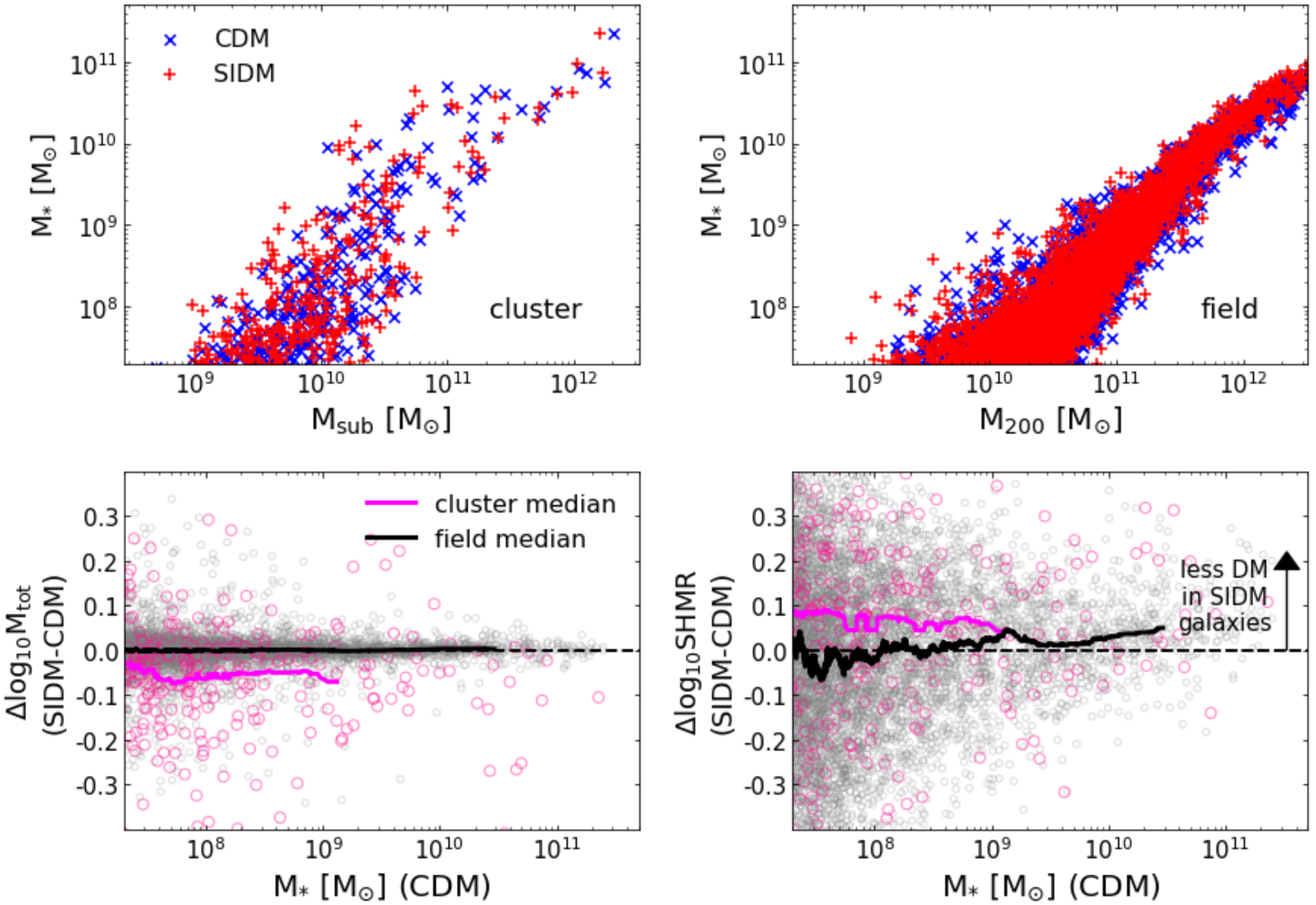
We can see enhanced mass loss
due to DM self-interactions

What do the SHMRs in the simulations look like?

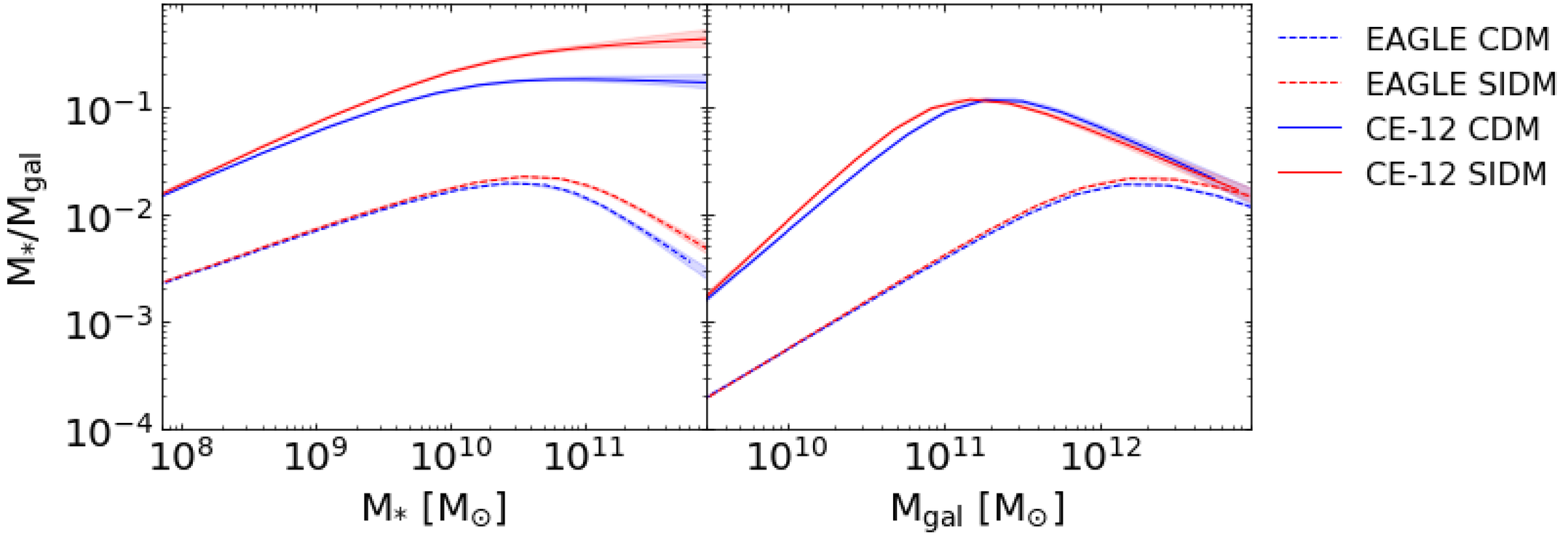
Effects hard to see

differences ~15%, but:
shape similar

Hard to observe!



SHMR shapes similar



precise masses needed to see difference?

In other words...

- Self-interactions enhance mass loss
- SHMR differences between SIDM & CDM ~15%
  --> Not insignificant, but no shape difference: challenging to observe
- Cross-section used arguably already ruled out
  --> Observational signatures for smaller cross-sections even harder to find

Perhaps in the future look at more clusters?
Next project: halo shapes!

And also: **SuperBIT**!

SuperBIT

The Super-pressure Balloon-borne Imaging Telescope

- Wide-field (0.4 deg) instrument
- Visible-to-near-UV bands (300-900 nm)
- Diffraction-limited resolution of 0.25 arc seconds.

Use strong and weak lensing to map distribution
of dark matter around 100s of galaxy clusters

Restores capability in era of IR missions after HST

SuperBIT

Data retrieval

Retrieve data midflight:

- Mitigate risk of total data loss
- Use early results to optimise later data acquisition

Via satellite: bandwidth too low & expensive

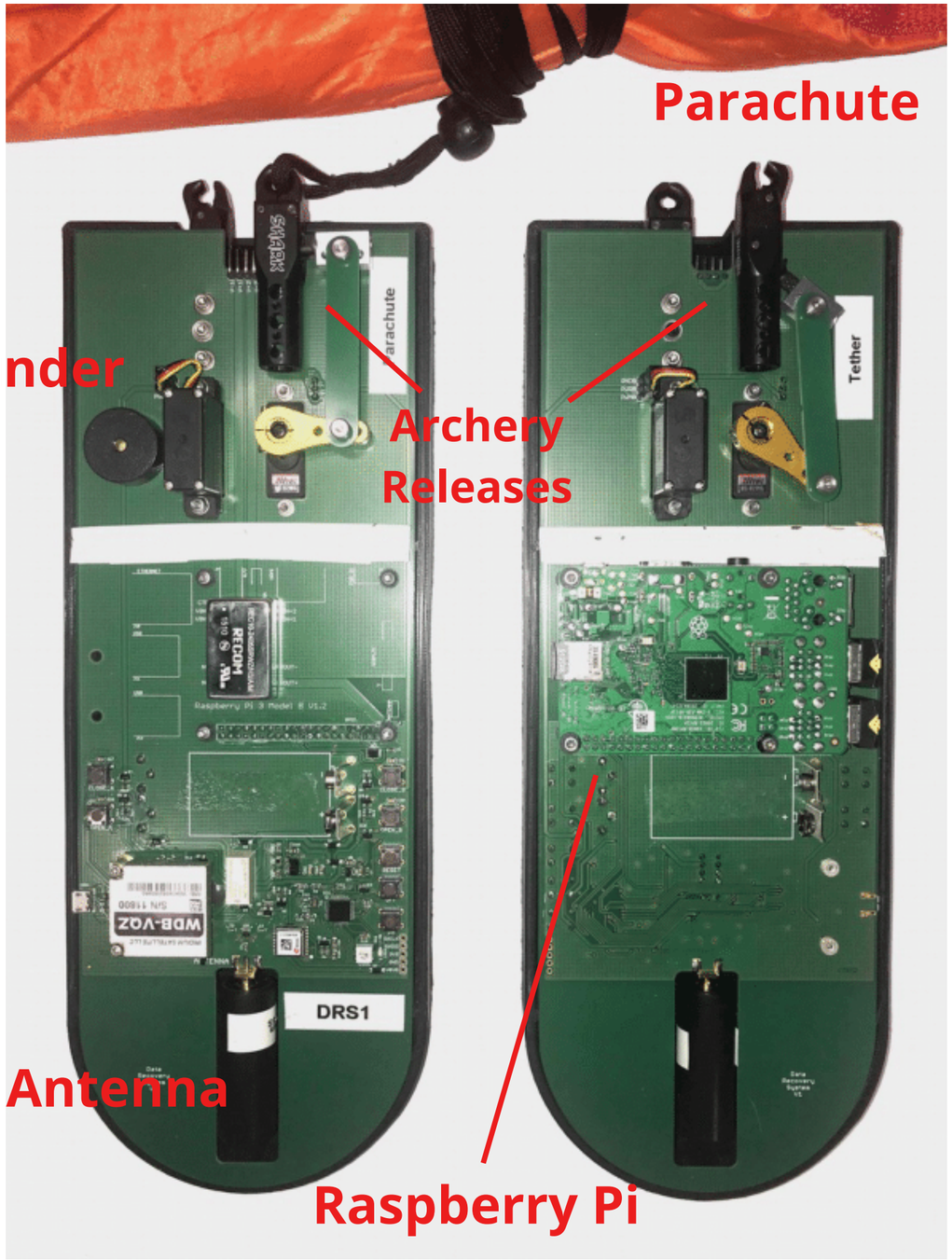
The (SuperBIT)
Data Retrieval System:
DRS

The DRS

A toolkit of hardware & software to retrieve assets from a stratospheric balloon platform

SD cards on parachutes!

Can hold up to ~5 TB



Landing Locations

Safety + Practical requirements
(We cannot just drop stuff from the sky)

↓

Need to know where it will land

↓

PyBalloon: 1) predict where parachutes will land (safety)
2) estimate where it did land (recovery)

Calibrate using past flights

PyBalloon

drag eq. -> descent speeds

+

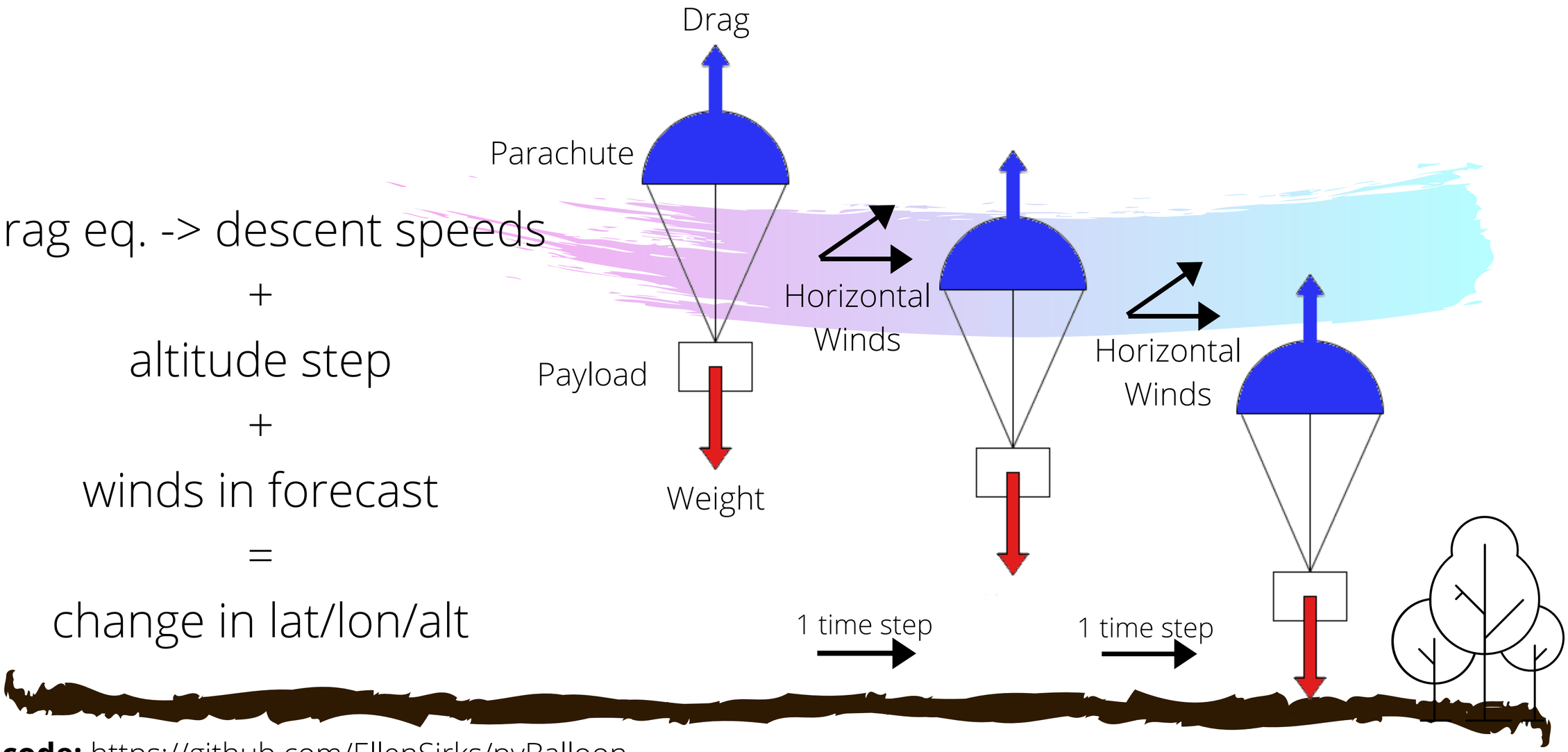
altitude step

+

winds in forecast

=

change in lat/lon/alt



The code: https://github.com/EllenSirks/pyBalloon

SuperBIT 2019 Commissioning Flight

- Launch: September 17, 2019 at 20:34 GMT-4
- Centre National d'Études Spatiales (CNES) through the Canadian Space Agency (CSA)
- Launch Site: Timmins, Ontario
- Flight termination: September 18, 2019 at ~14:00 GMT-4

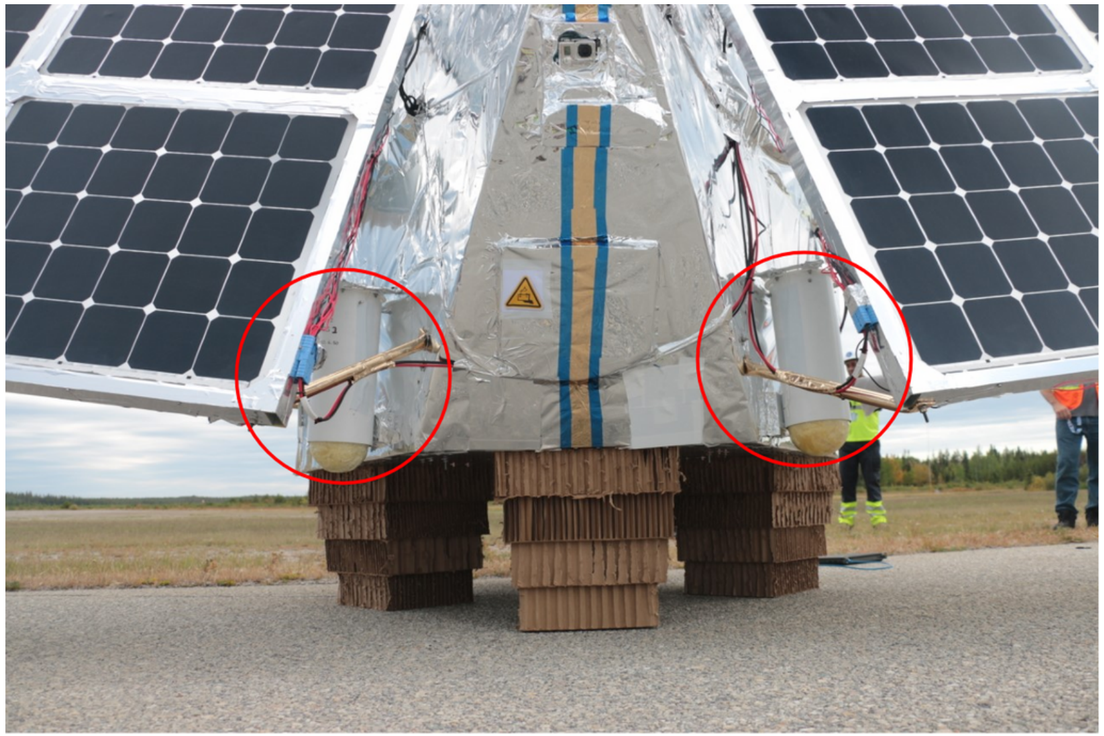
~3.5 hours of science observations

The DRS Test

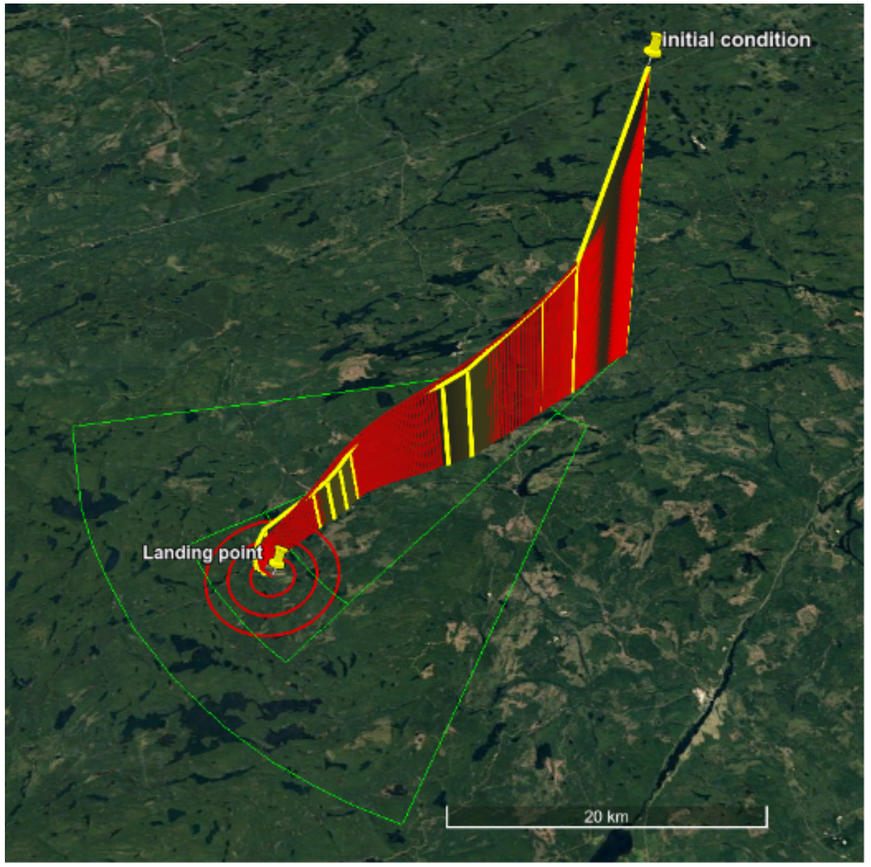
Dropped two DRS capsules: 1 TB of storage instead of max. 5 TB.

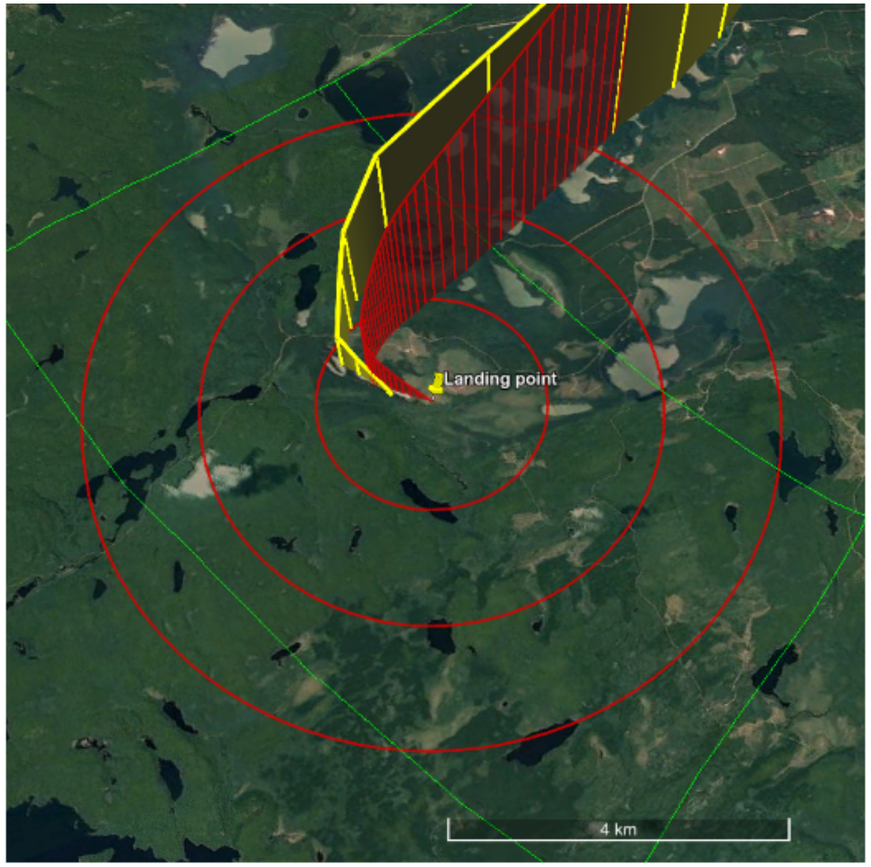
- First: just before ceiling
- Second: just before descent

used prediction software
to target an area of forest
without lakes or population
+ close to road



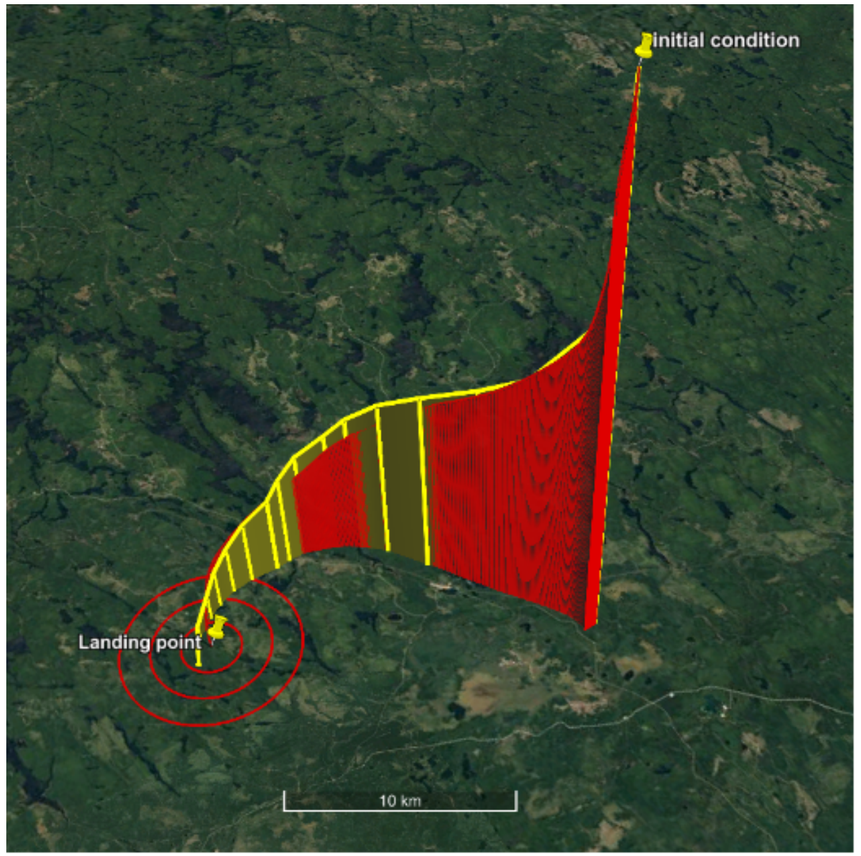
Capsule 1

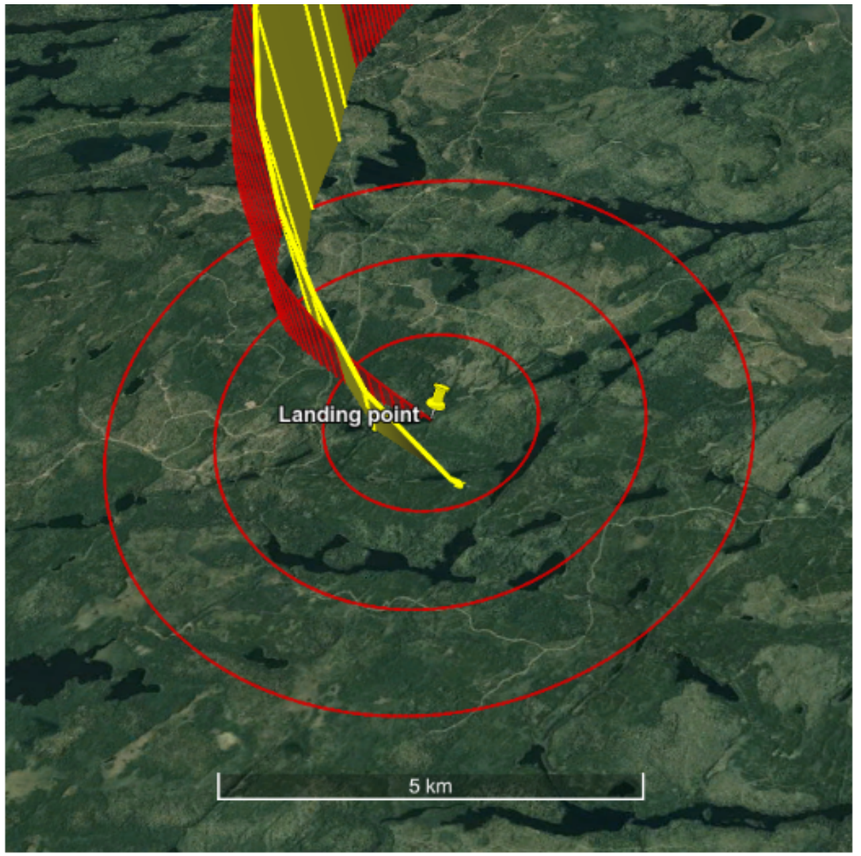




Deviation: ~600m

Capsule 2





Deviation: ~1100m

Recovery

Found in 5 minutes!

THANK YOU!