ダークマター欠乏銀河形成条件の解析

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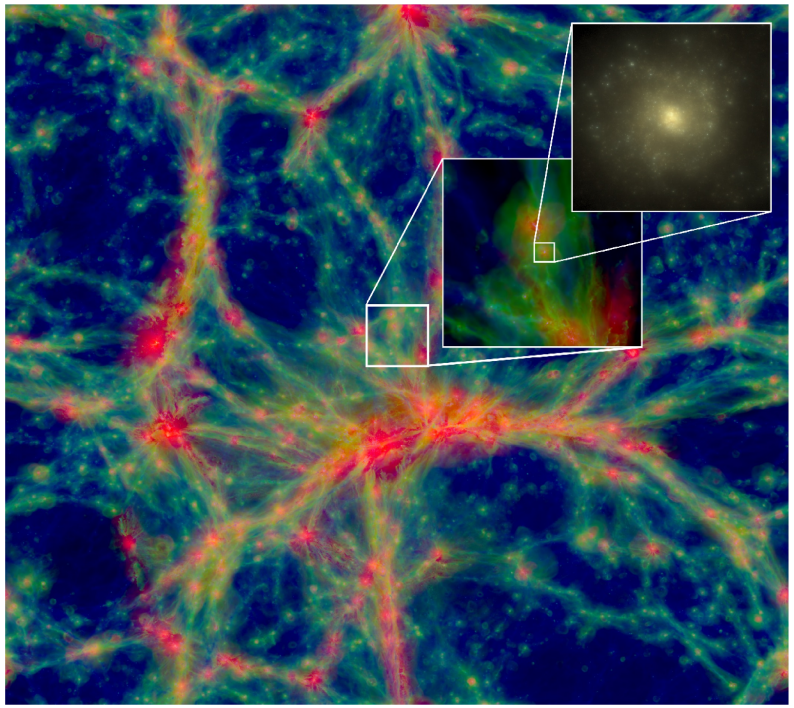
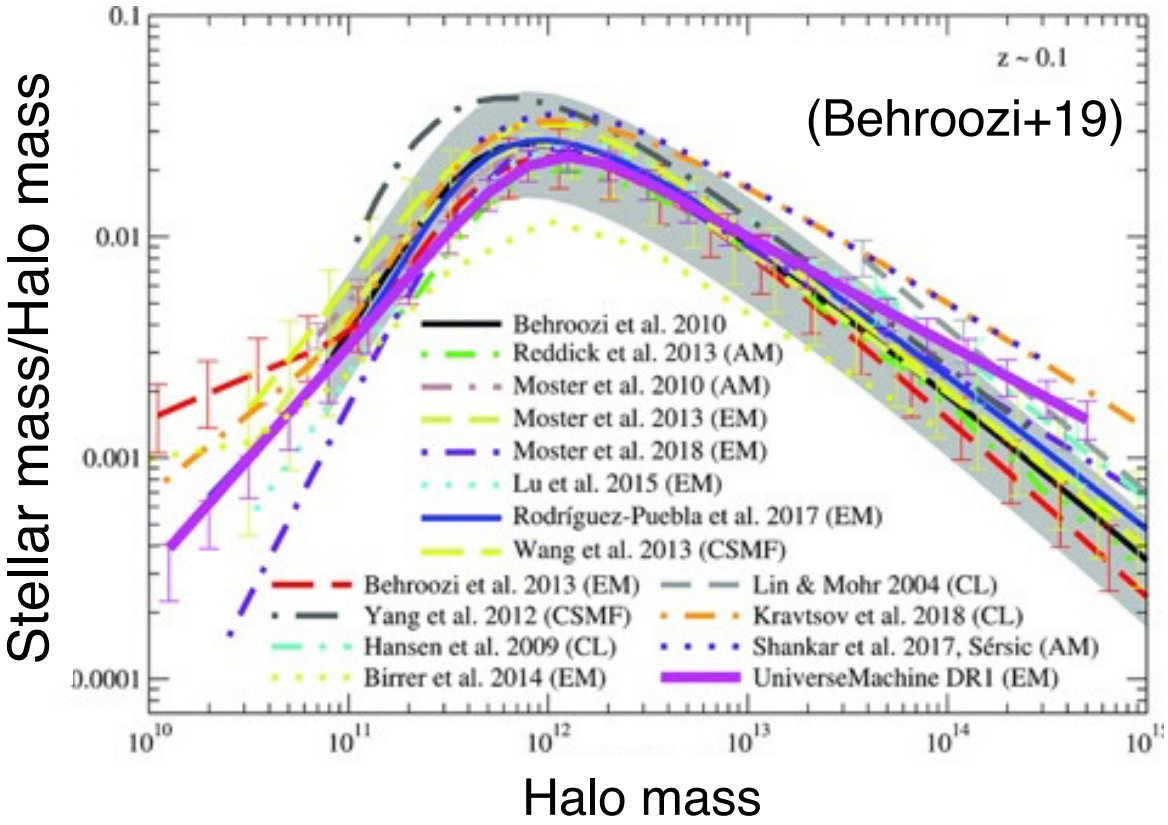
Galaxy formation in CDM paradigm



(Schaye et al. 2015)

stellar mass-halo mass relation



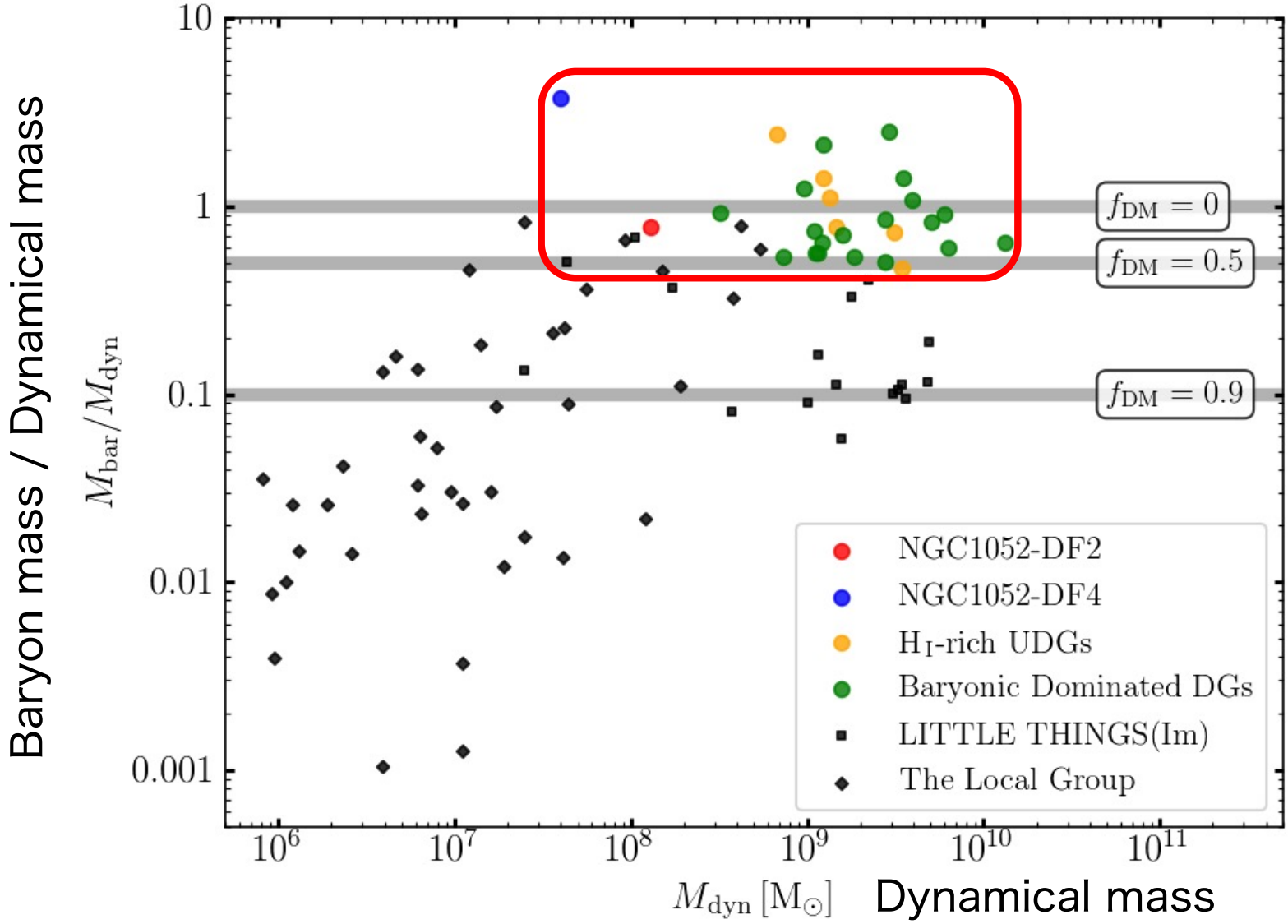
MW-like galaxy : $M_\star \sim 10^{10}\,\mathrm{M}_\odot$, $M_{\mathrm{DM}} \sim 10^{12}\,\mathrm{M}_\odot$

dwarf galaxy : $M_\star \sim 10^{8}\,\mathrm{M}_\odot$, $M_{\mathrm{DM}} \sim 5\times 10^{10}\,\mathrm{M}_\odot$

Dark-Matter-Deficient Galaxies ($M_{\mathrm{baryon}} \gtrsim M_{\mathrm{DM}}$) were found.

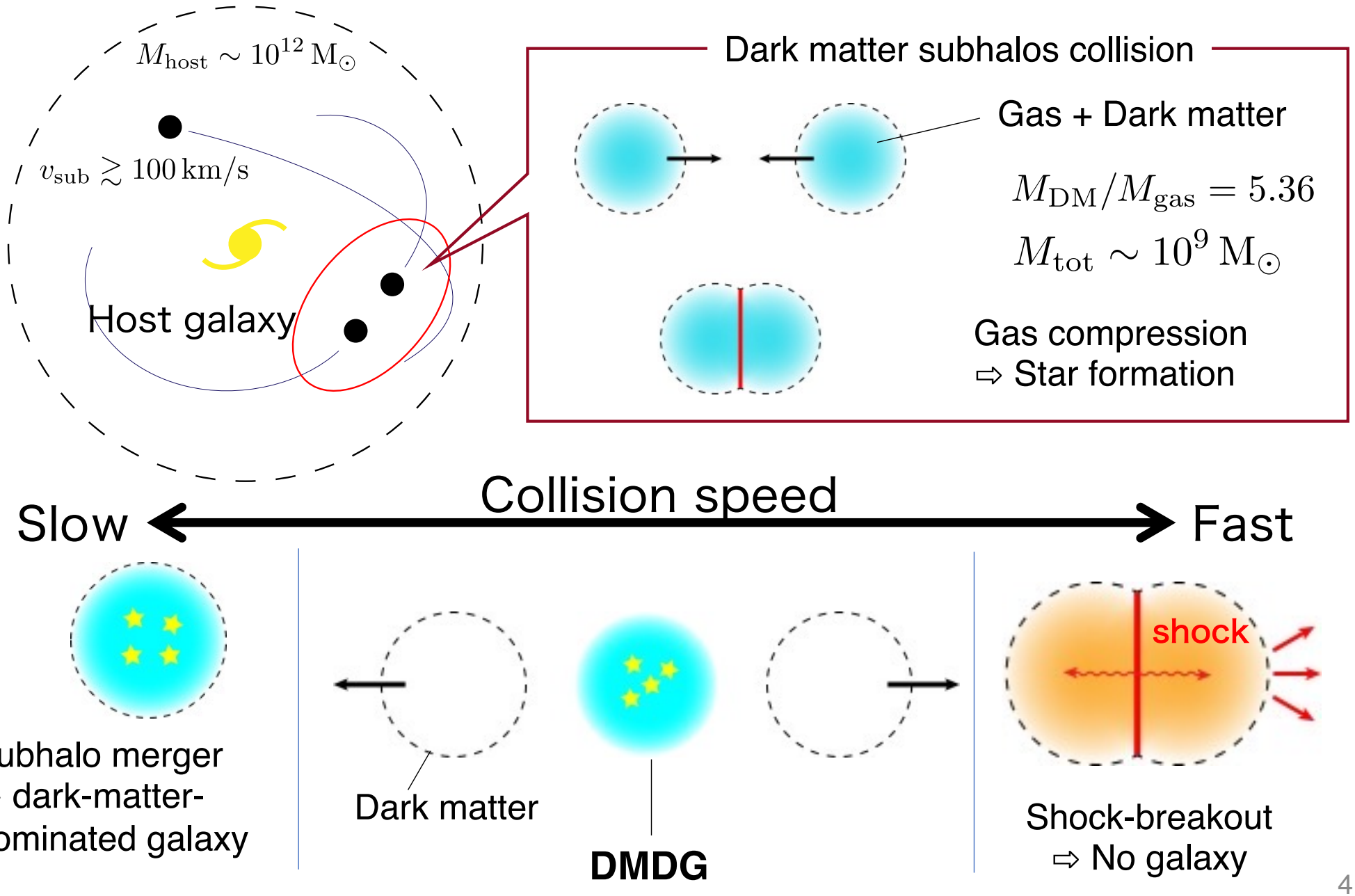
Dark-Matter-Deficient Galaxies (DMDGs)

(van Dokkum+18,19, Mancera Piña+19, Guo+20)

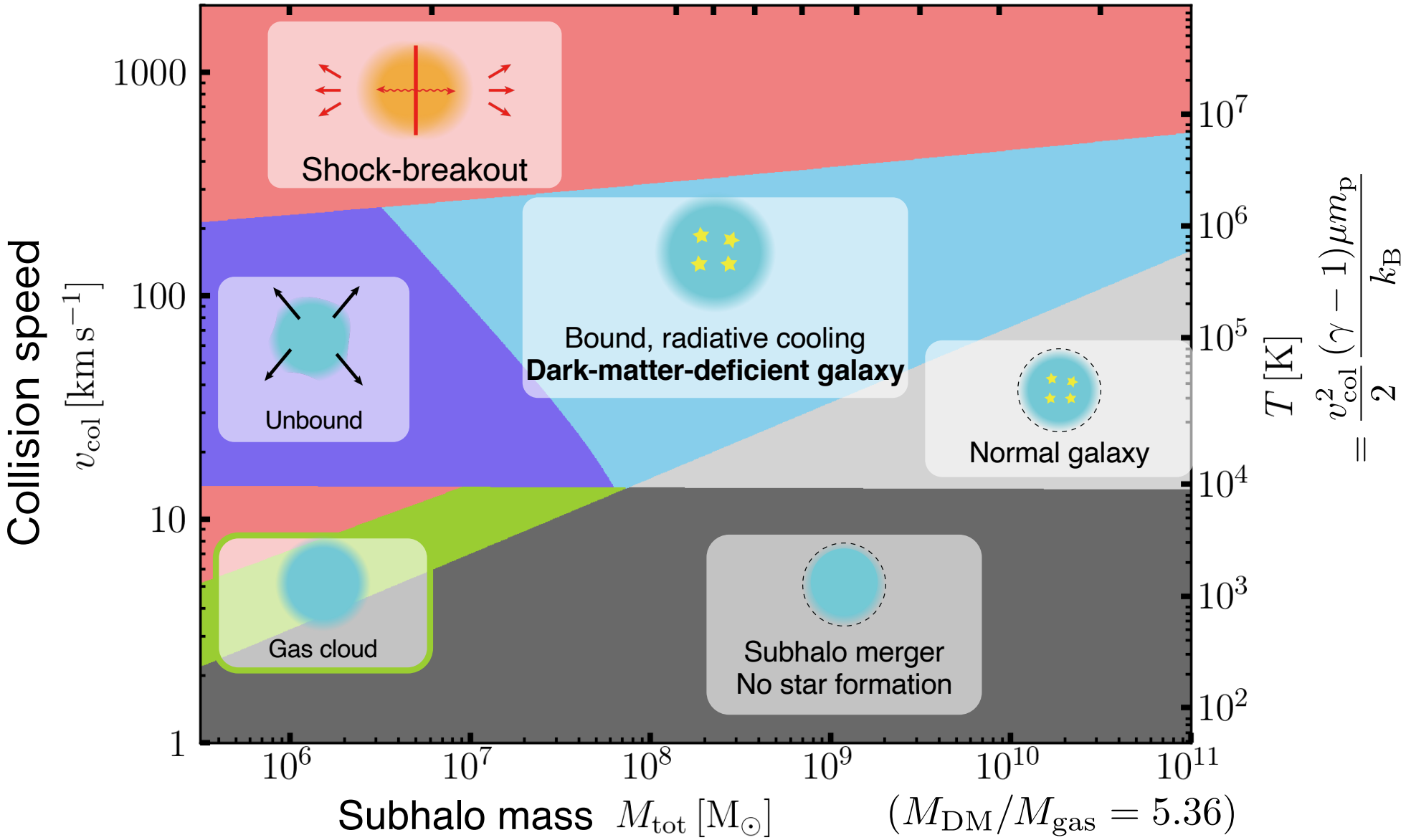


How do they form in a dark-matter-dominated universe?

Dark-matter-deficient galaxy (DMDG) formation model

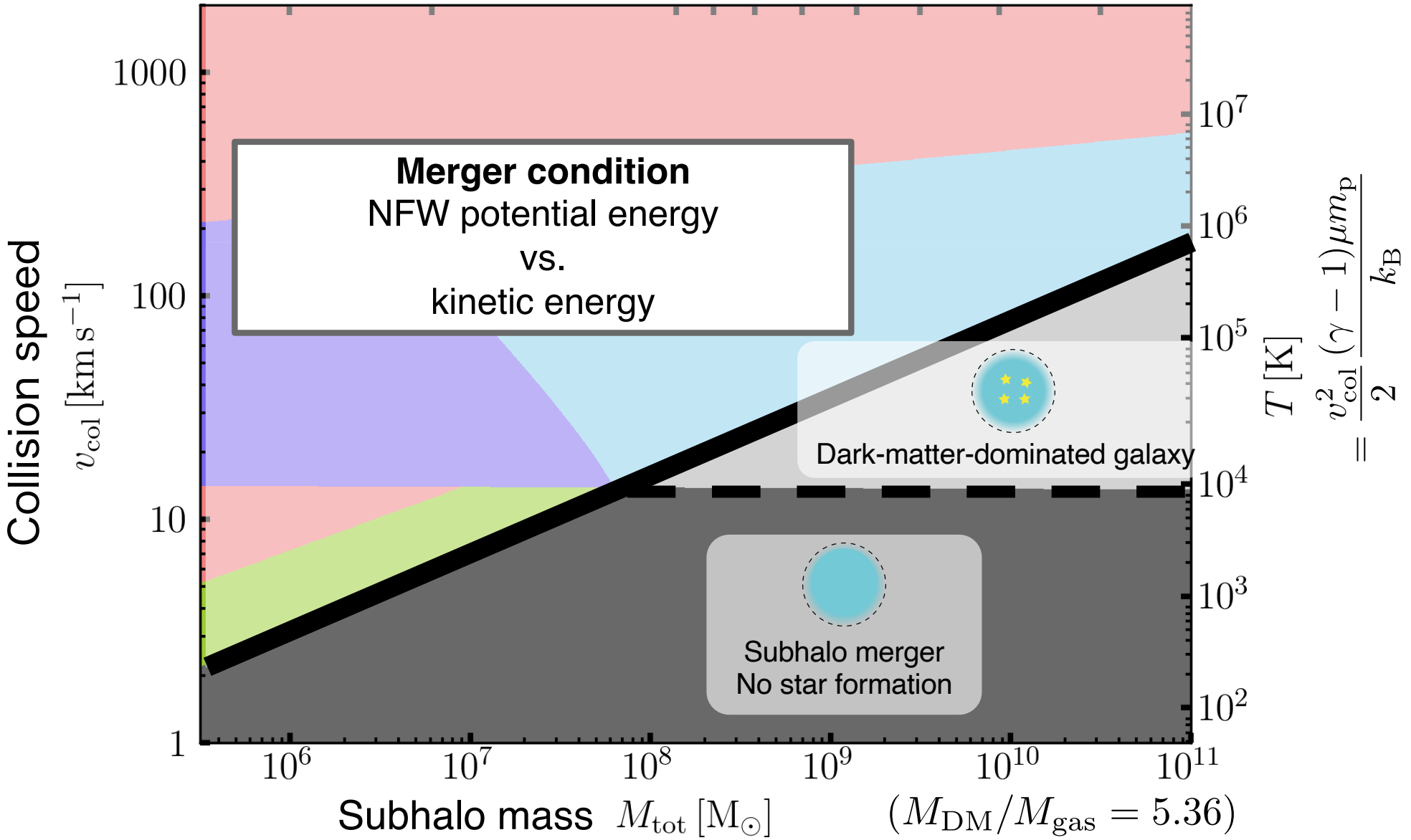


Analytical model for galaxy formations



Cooling rate: primordial gas in collisional ionization equilibrium

Analytical model for galaxy formations



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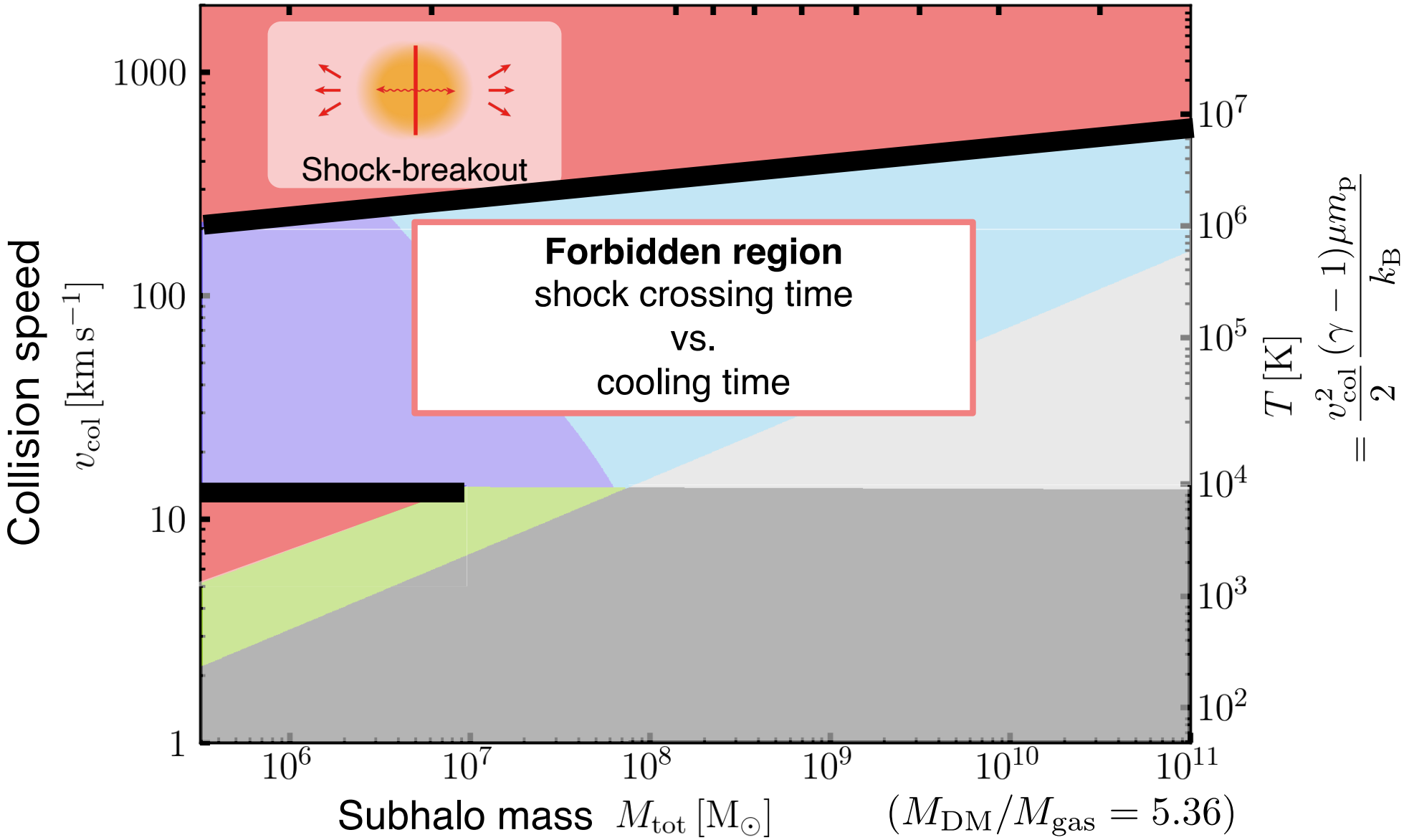

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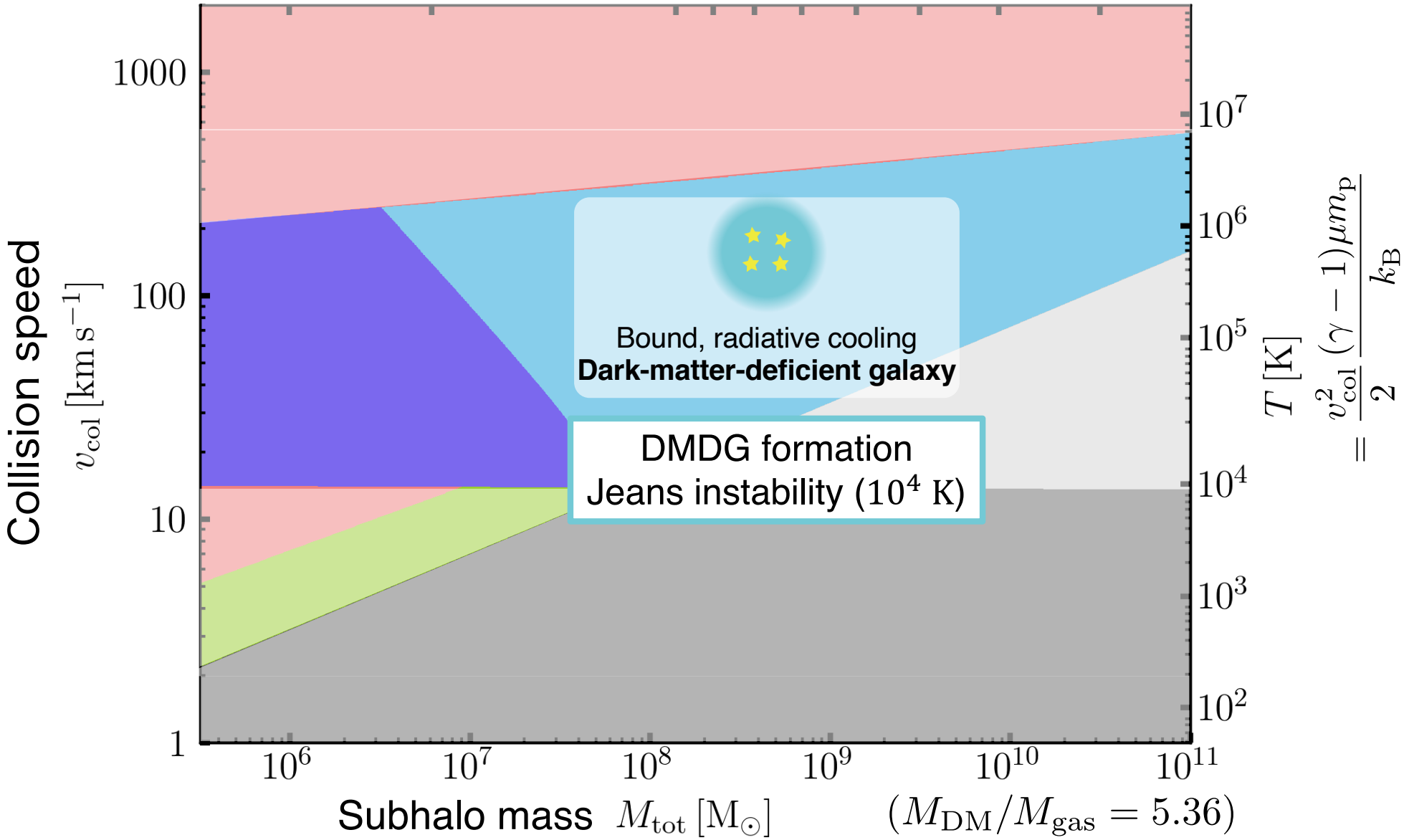
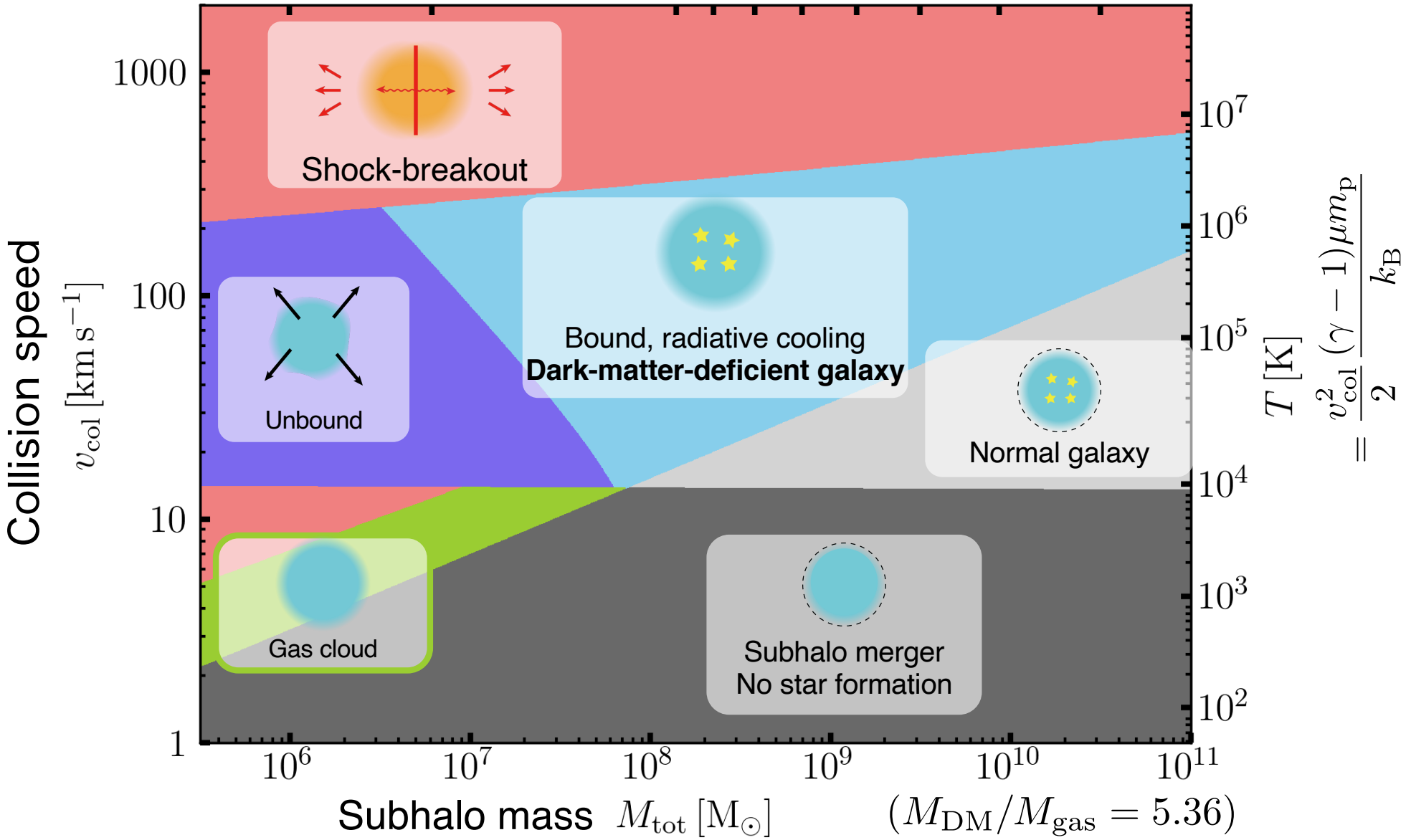


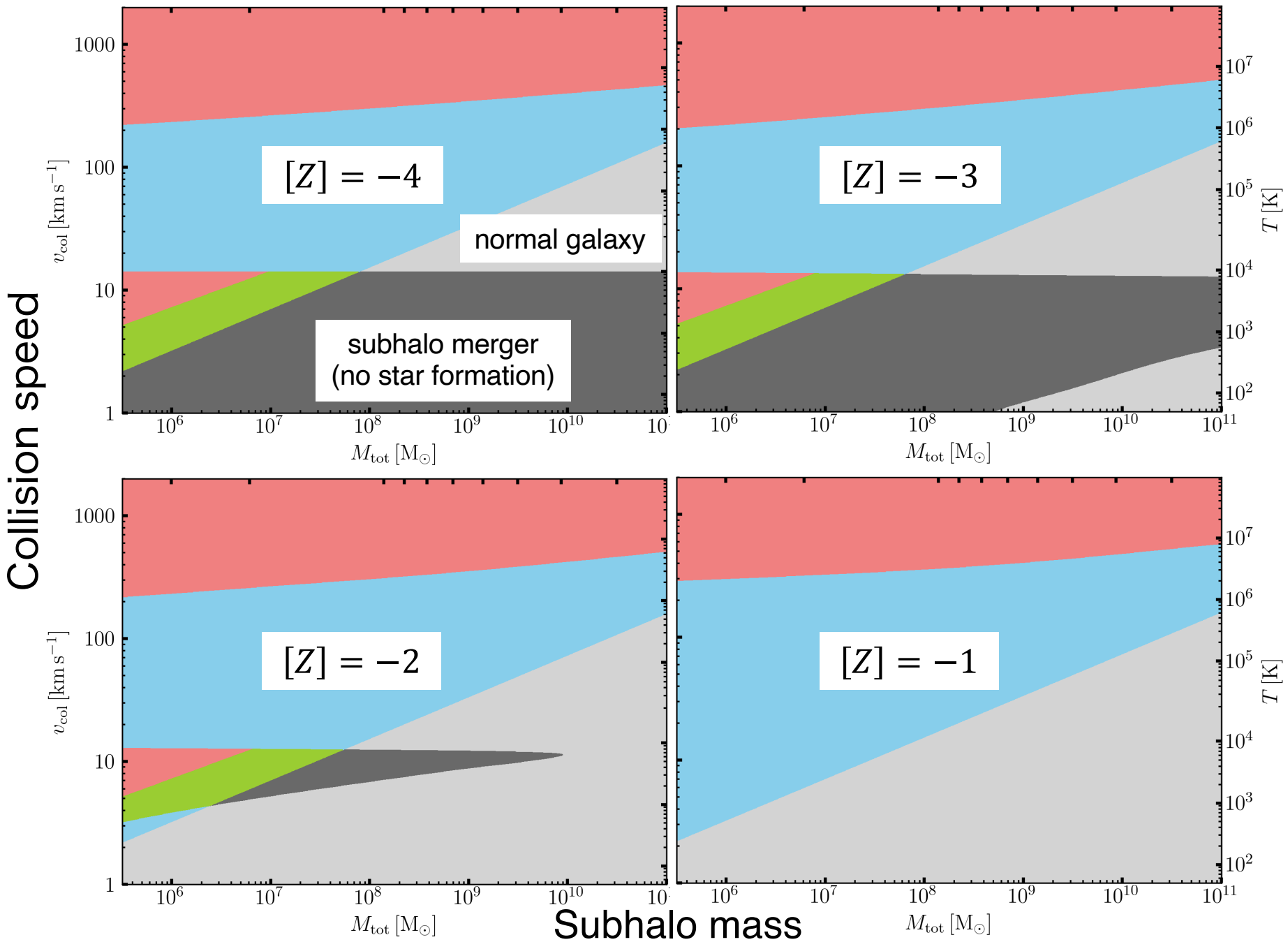
Cooling rate: primordial gas in collisional ionization equilibrium

Analytical model for galaxy formations

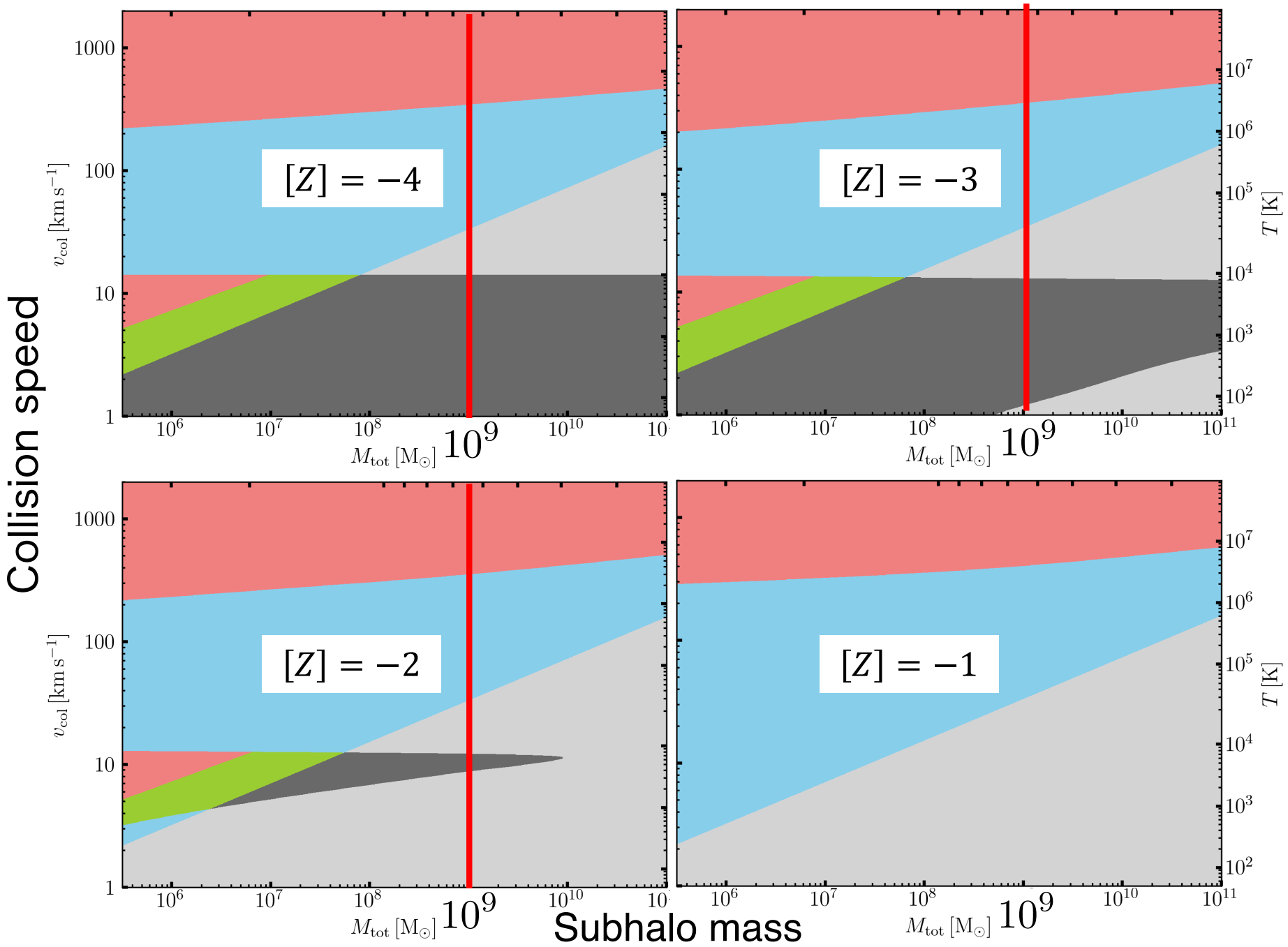


Cooling rate: primordial gas in collisional ionization equilibrium

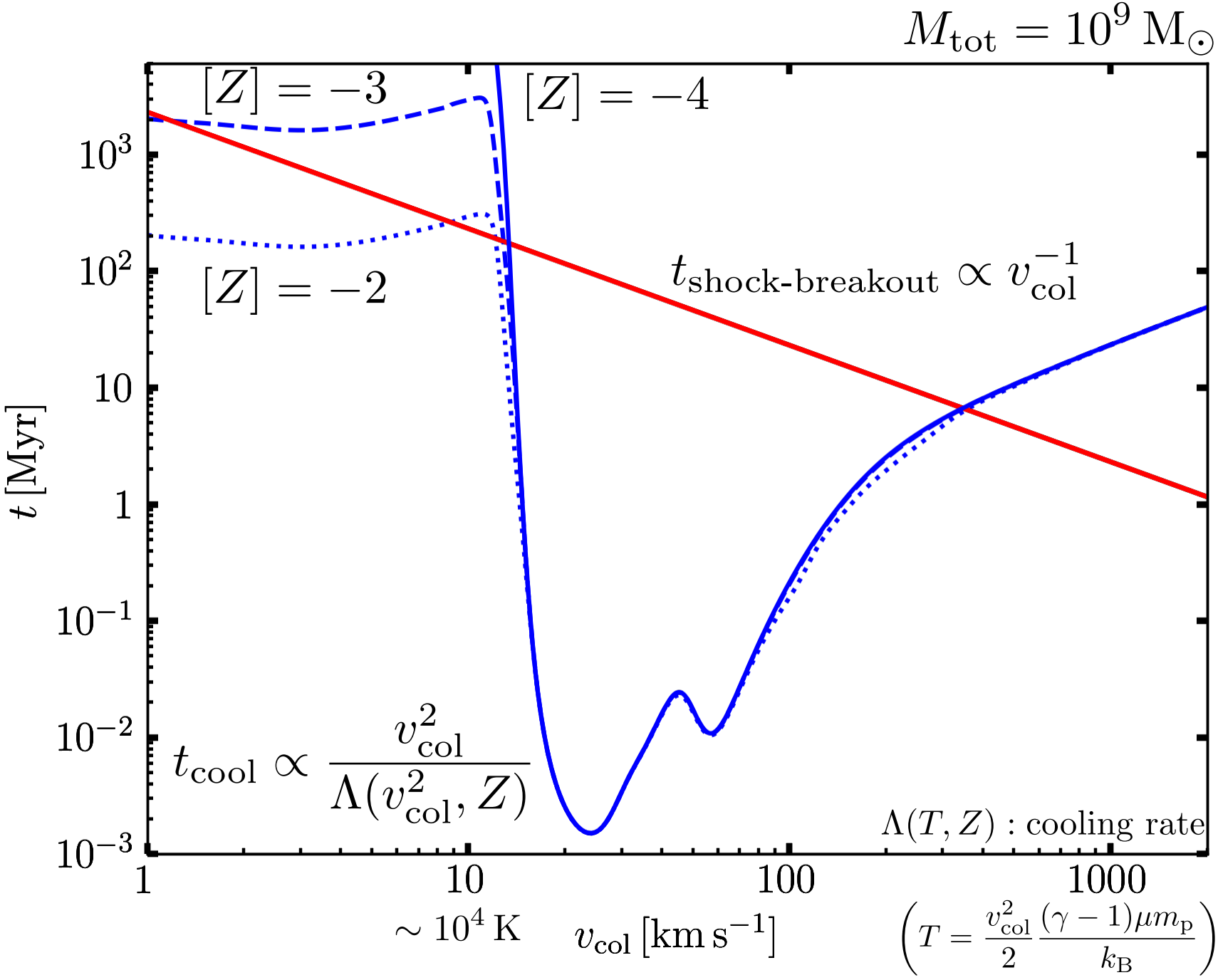
Metallicity dependence of analytical model



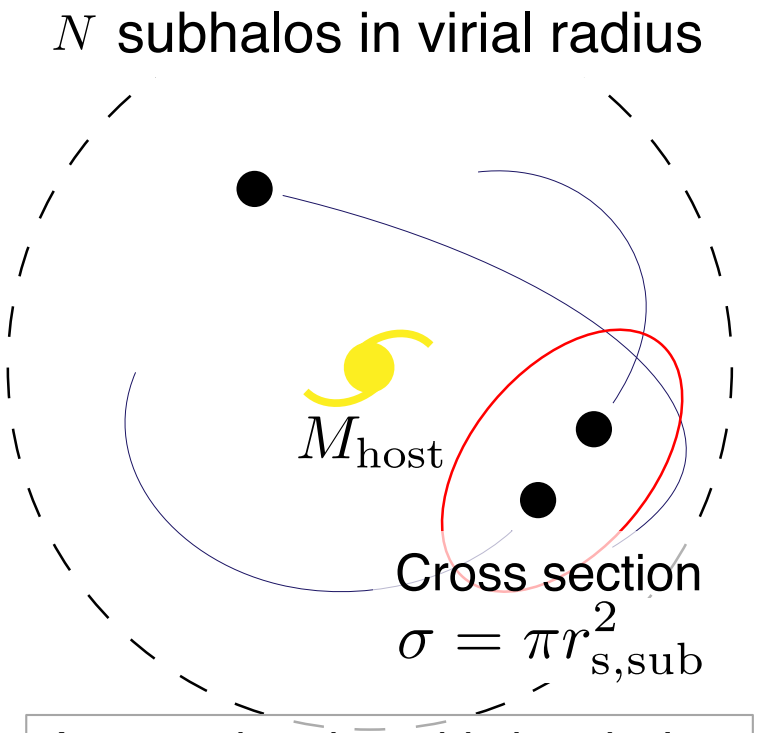
Metallicity dependence of analytical model



Metallicity dependence of cooling time



Estimation of collision frequency



Assume that the subhalo velocity corresponds to the velocity distribution function

- Assume the NFW number density of subhalos

$$n(r) = \frac{N\rho_0}{M_{\rm host}x(1+x)^2}, \quad x = \frac{r}{r_{\rm s,host}}$$

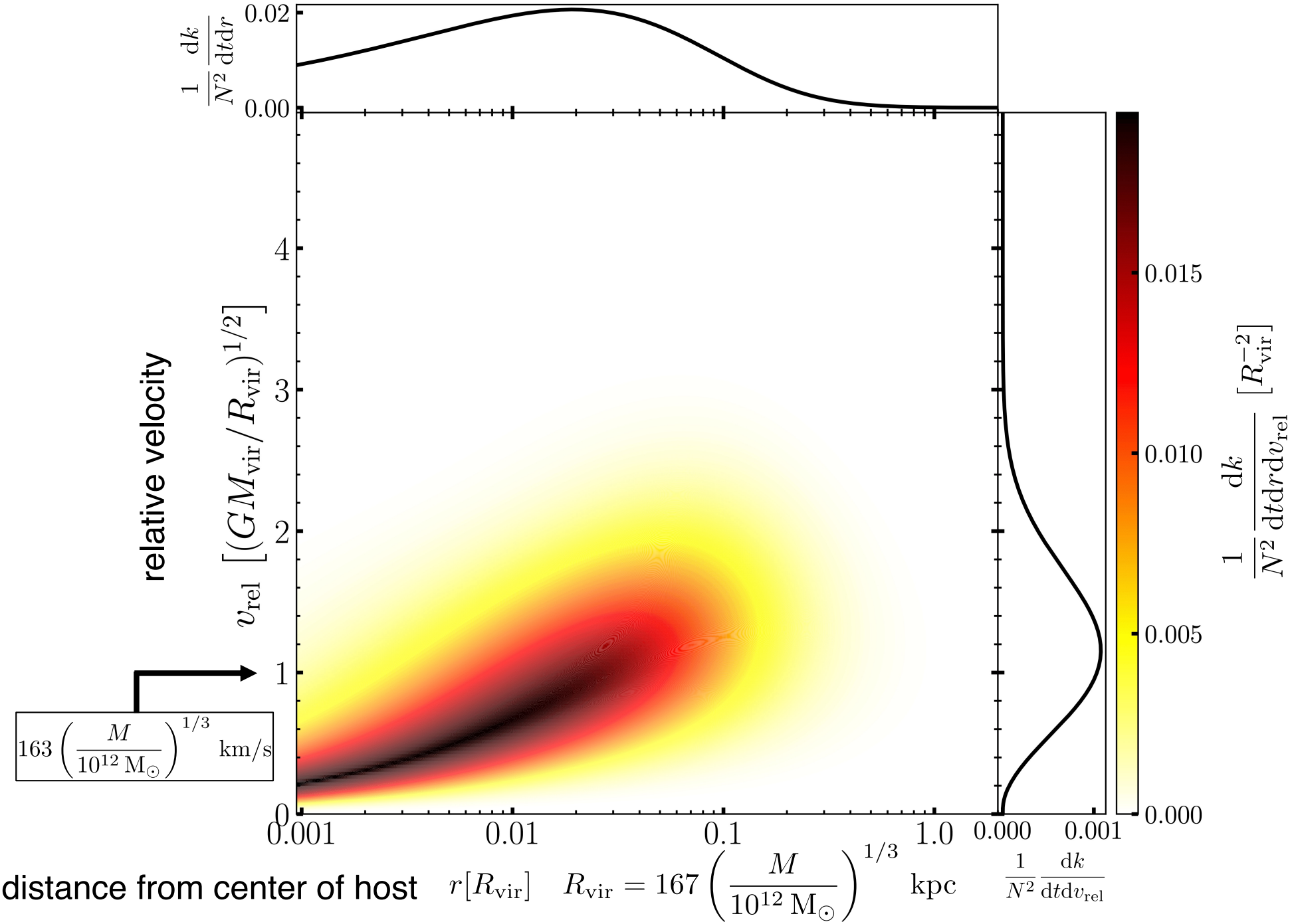
- Velocity distribution function of the NFW profile + Two-body problem

→ Probability distribution of relative velocity $P_{r,\rm rel}(v_{\rm rel})$

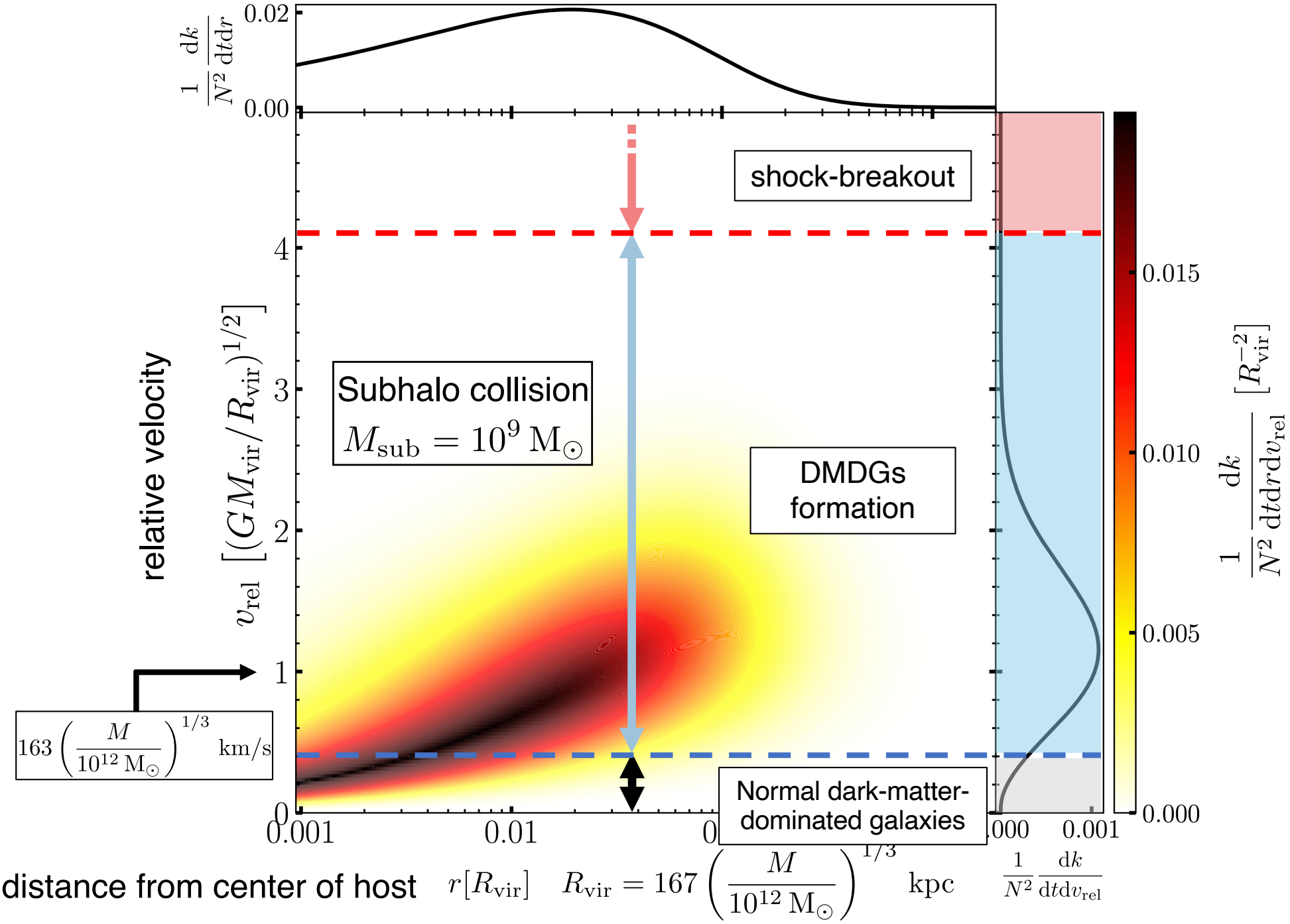
Collision frequency per time

$$\frac{1}{N^2}\frac{{\rm d}k}{{\rm d}t} = \int \frac{1}{2}\cdot\sigma\cdot v_{\rm rel}P_{r,\rm rel}(v_{\rm rel}){\rm d}v_{\rm rel}\cdot\left[\frac{n(r)}{N}\right]^2 4\pi r^2{\rm d}r$$

Dependence of Collision Frequency



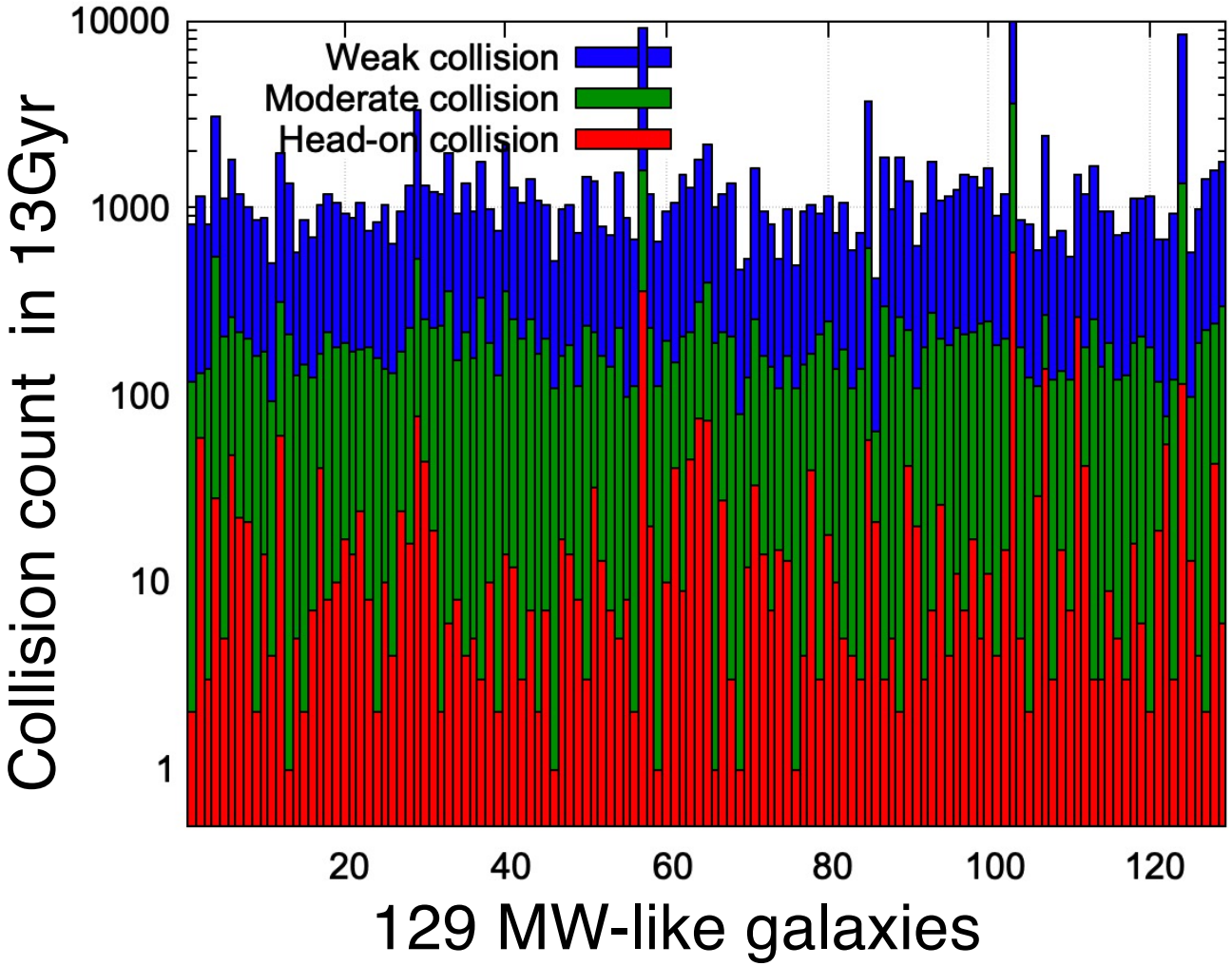
Dependence of Collision Frequency



Collision count in MW-like galaxies

(Kazuno, Mori & Otaki in prep.)

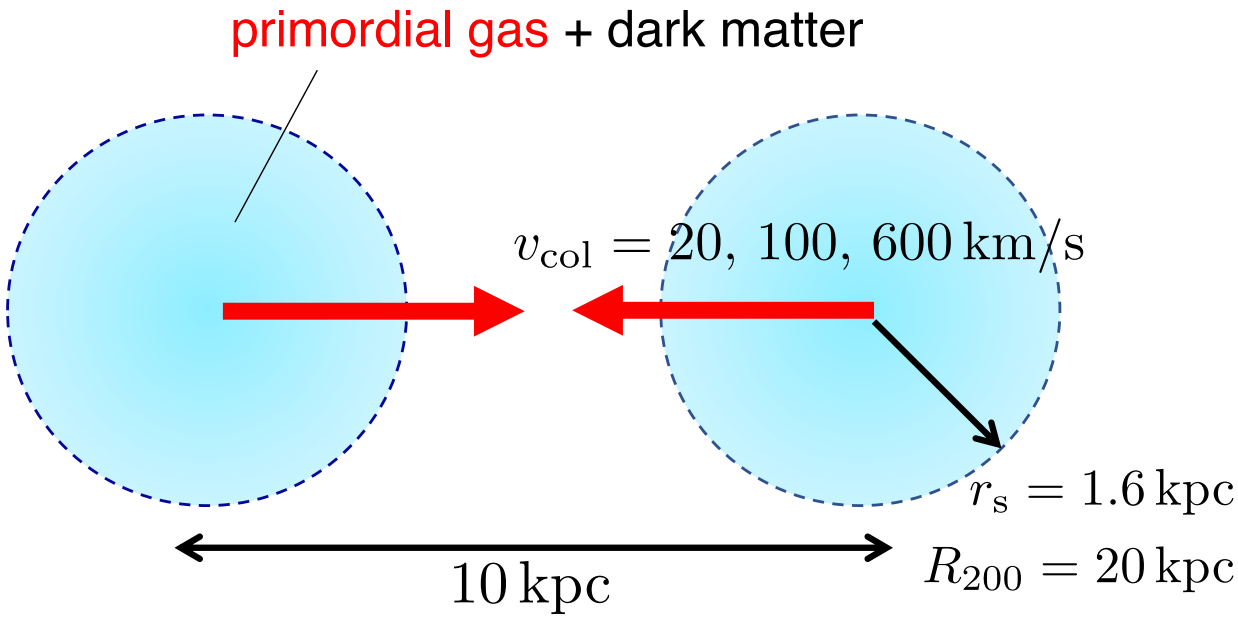
1. Select MW-like galaxies from Shin-Uchuu Simulation
   (Ishiyama et al. 2021)
2. Count the number of subhalo collisions in MW-like galaxies



about 10 head-on collisions in 13Gyr

Initial Condition (N-body + SPH)

Dark matter subhalos collision



A subhalo

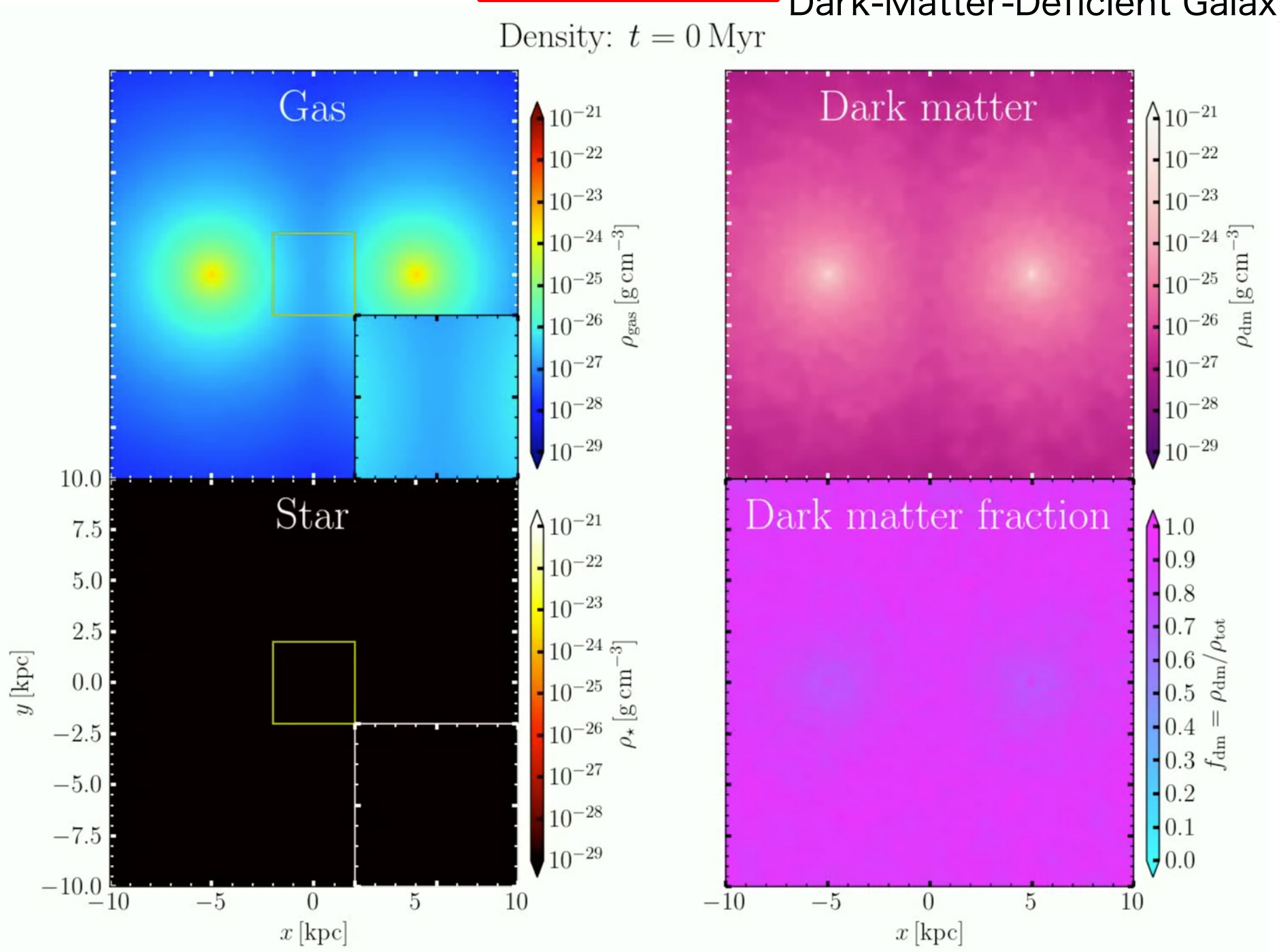
$$M_{\rm tot} = 10^9\,{\rm M}_\odot$$
$$M_{\rm DM} = 8.43 \times 10^8\,{\rm M}_\odot$$
$$M_{\rm gas} = 1.57 \times 10^8\,{\rm M}_\odot$$
$$M_{\rm DM}/M_{\rm gas} = 5.36$$

DM density: NFW profile
Gas density: hydrostatic equilibrium in DM

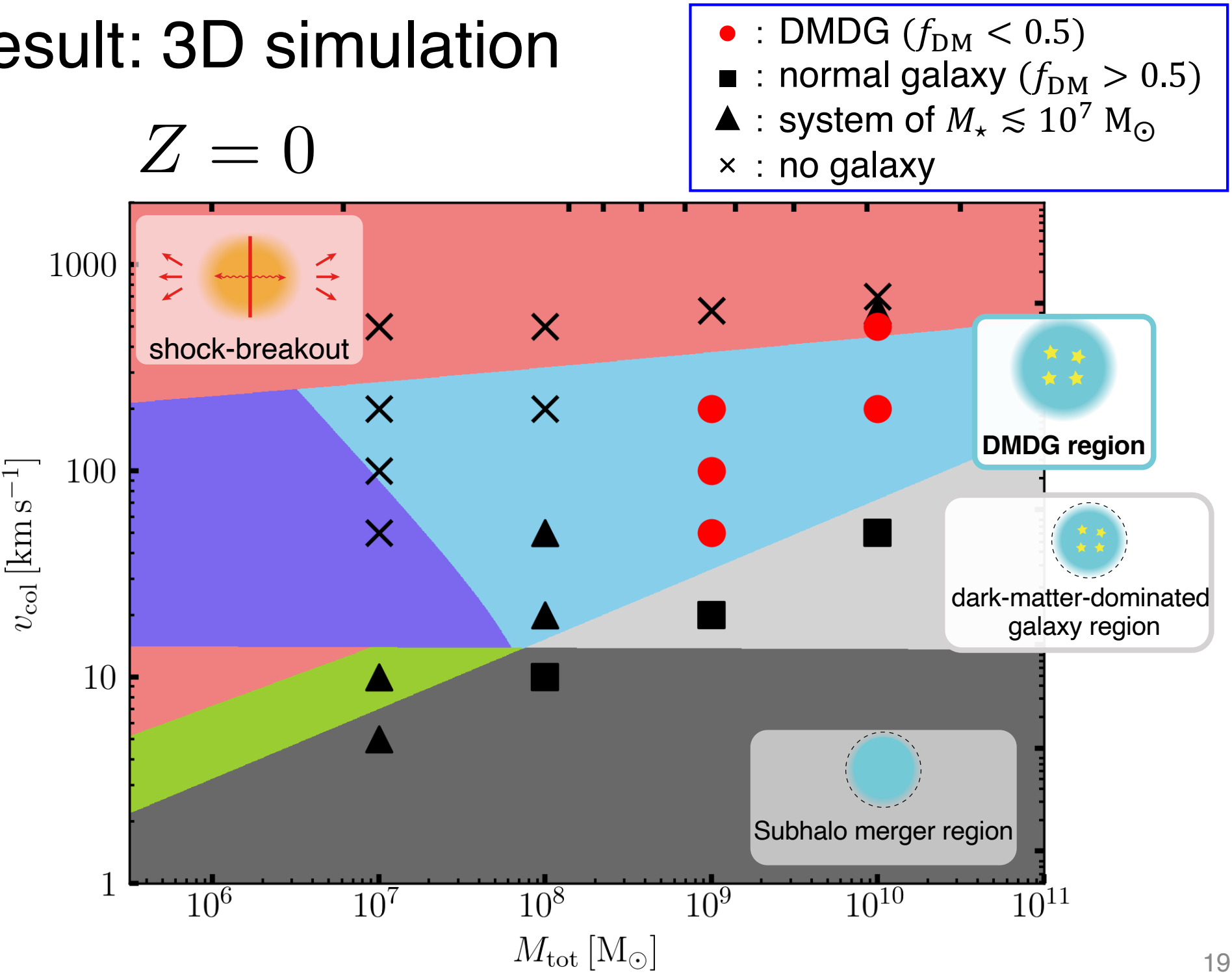
- Initial condition: MAny-component Galaxy Initializer (MAGI) (Miki & Umemura 18)
- Simulation code: Original (Otaki & Mori in prep.)
- Parallelization: A Framework Developing Parallel Particle Simulation (FDPS) (Iwasawa+16, Namekata+18)
- Supercomputer: Oakforest-PACS (JCAHPC; Tsukuba & Tokyo)
- Total number of particles: ~1,360,000

$v_{\rm col} = 100\,{\rm km/s}$

Dark-Matter-Deficient Galaxy



Result: 3D simulation



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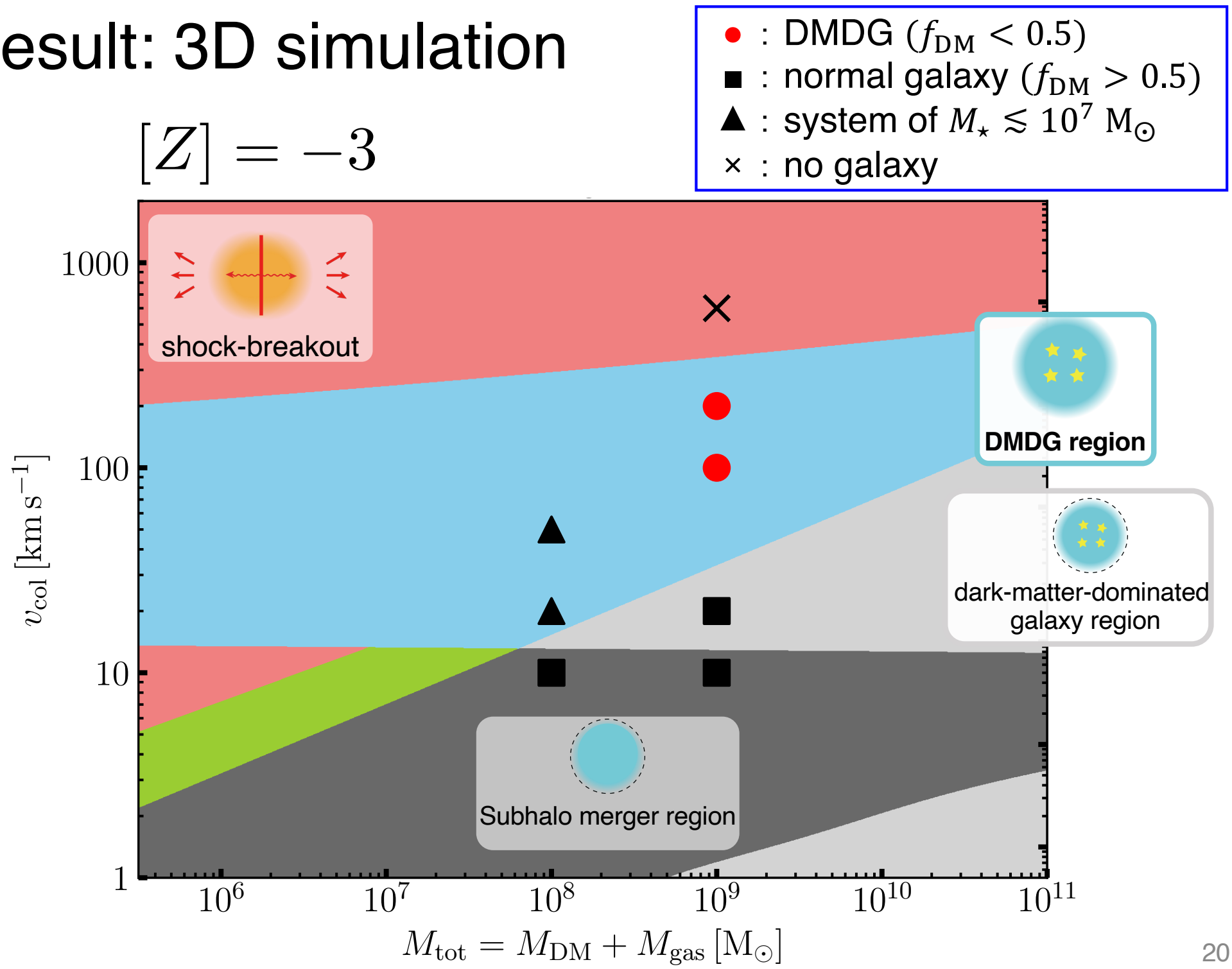

Summary

- We have systematically investigated the formation of dark-matter-deficient galaxies (DMDGs) using the analytical model of subhalo collisions.
- We have calculated the collision frequency of subhalos and found that collisions are likely to form DMDGs.
- Head-on collisions of subhalos successfully reproduce the basic properties such as total mass, scale and dark matter fraction of observed DMDGs.

Future work

- Effects of the supernova feedback
- Comparison with observed DMDGs
- Formation process in the off-center collisions