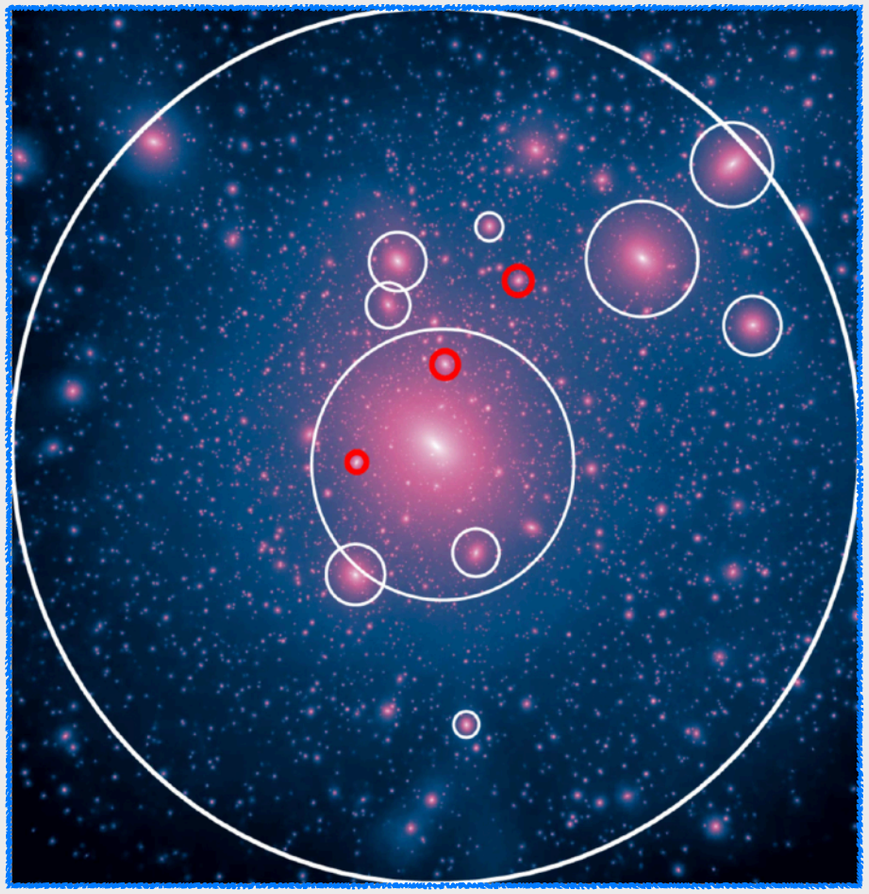
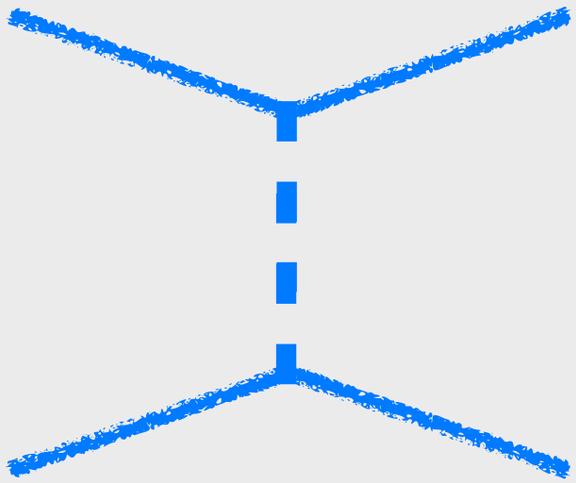
Astrophysical Probes of Dark Sector Physics

and signals of self-interacting dark matter





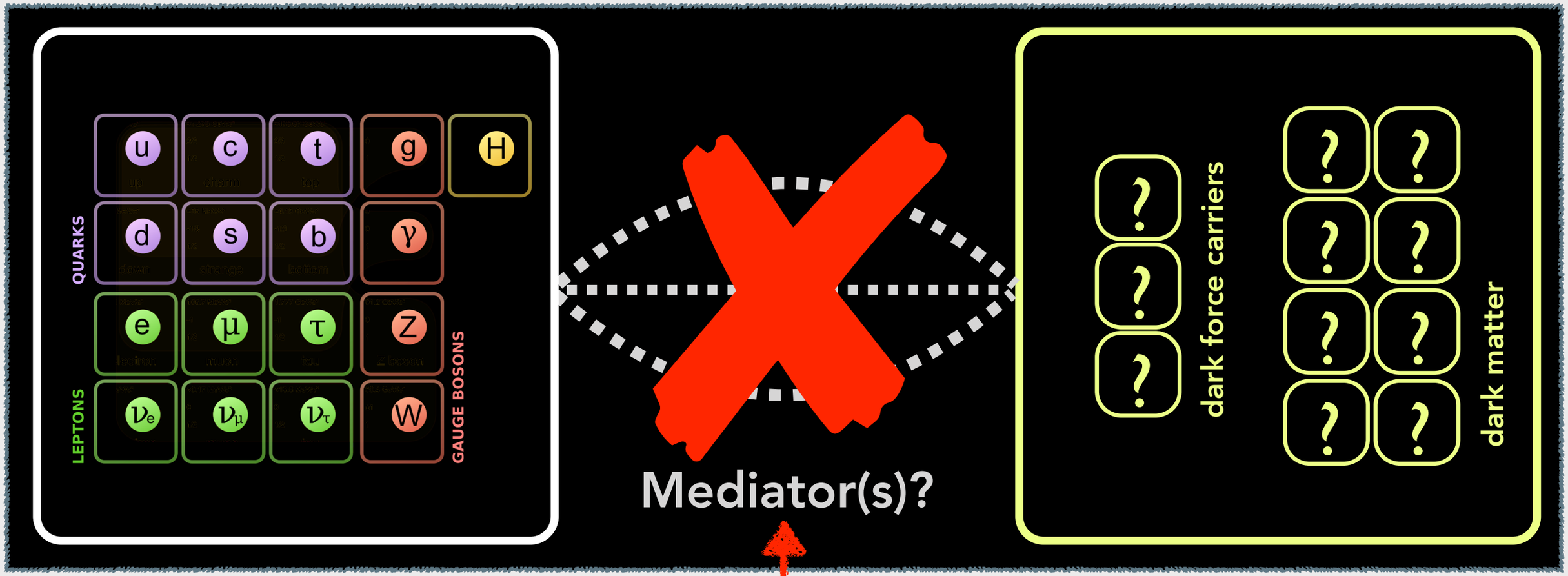
Oren Slone

arXiv numbers: 2108.03243, 2202.00012, 2206.12425, 2207.02861, 2402.12452

The Dark Sector

The Standard Model

The Dark Sector



“The nightmare scenario”

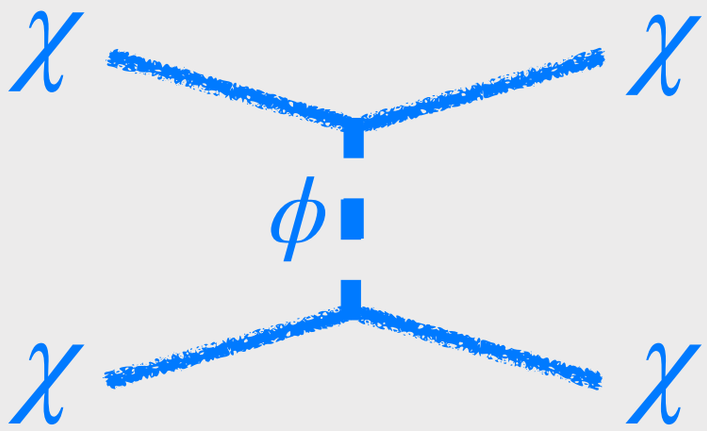
Particle Physicists

<u>This talk:</u>

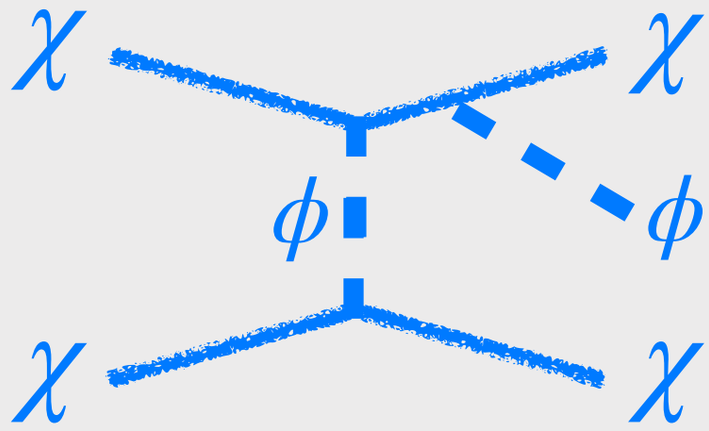
Turning the nightmare into a regular dream

Mapping dark sector micro-physics onto gravitational macro-physics

dark sector micro-physics

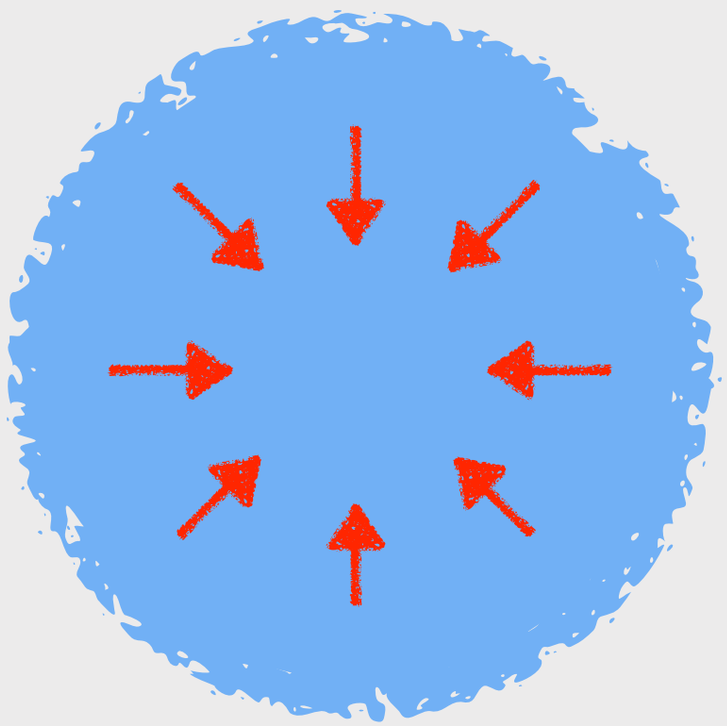


self interactions

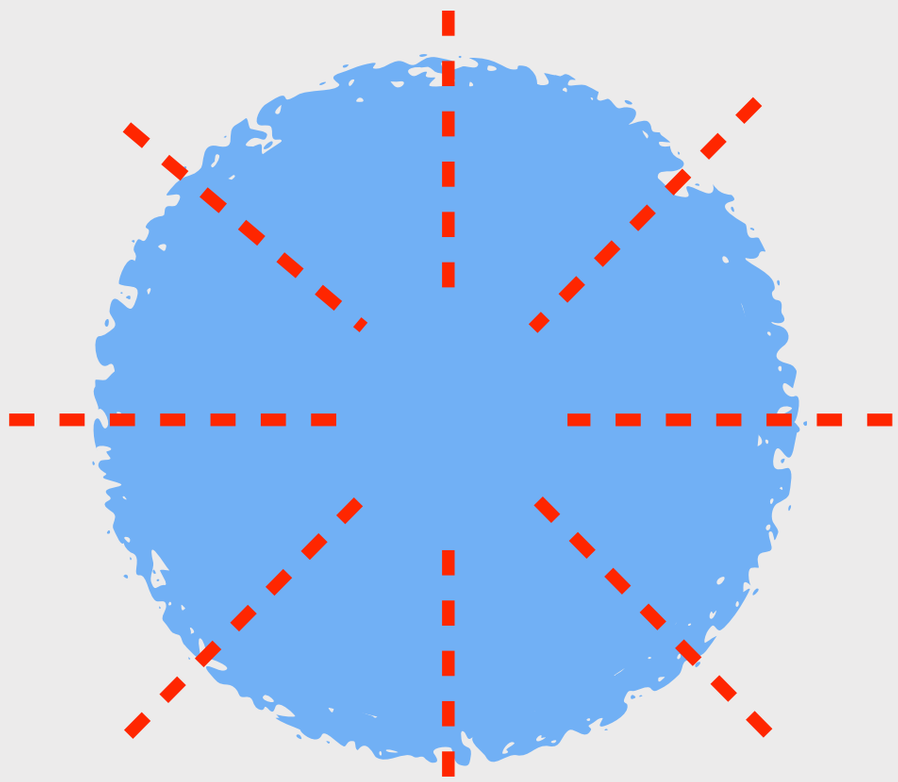


global dissipation

maps to dark matter macro-physics

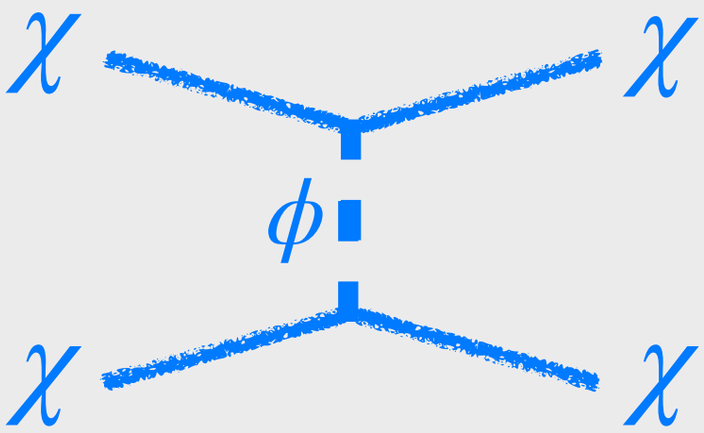


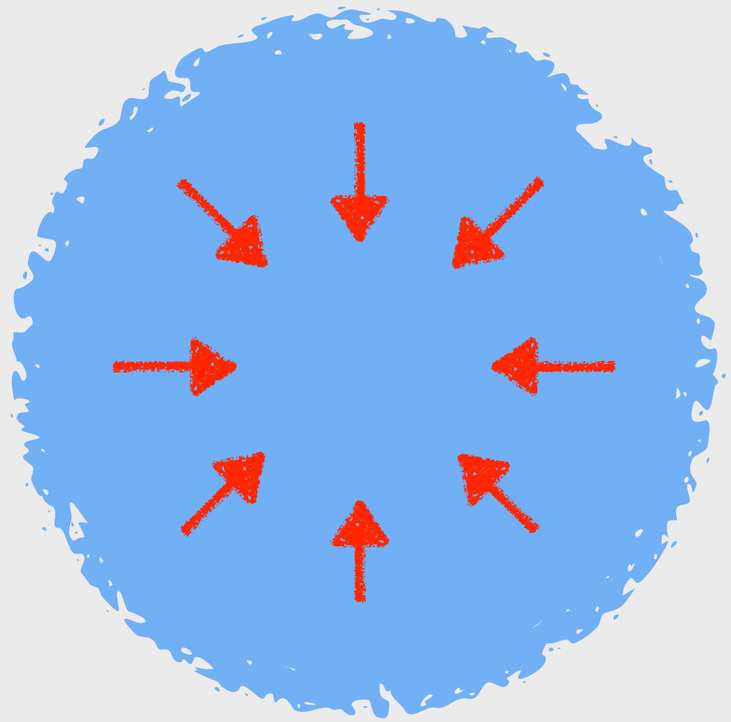
heat flow



cooling

Understand the mapping

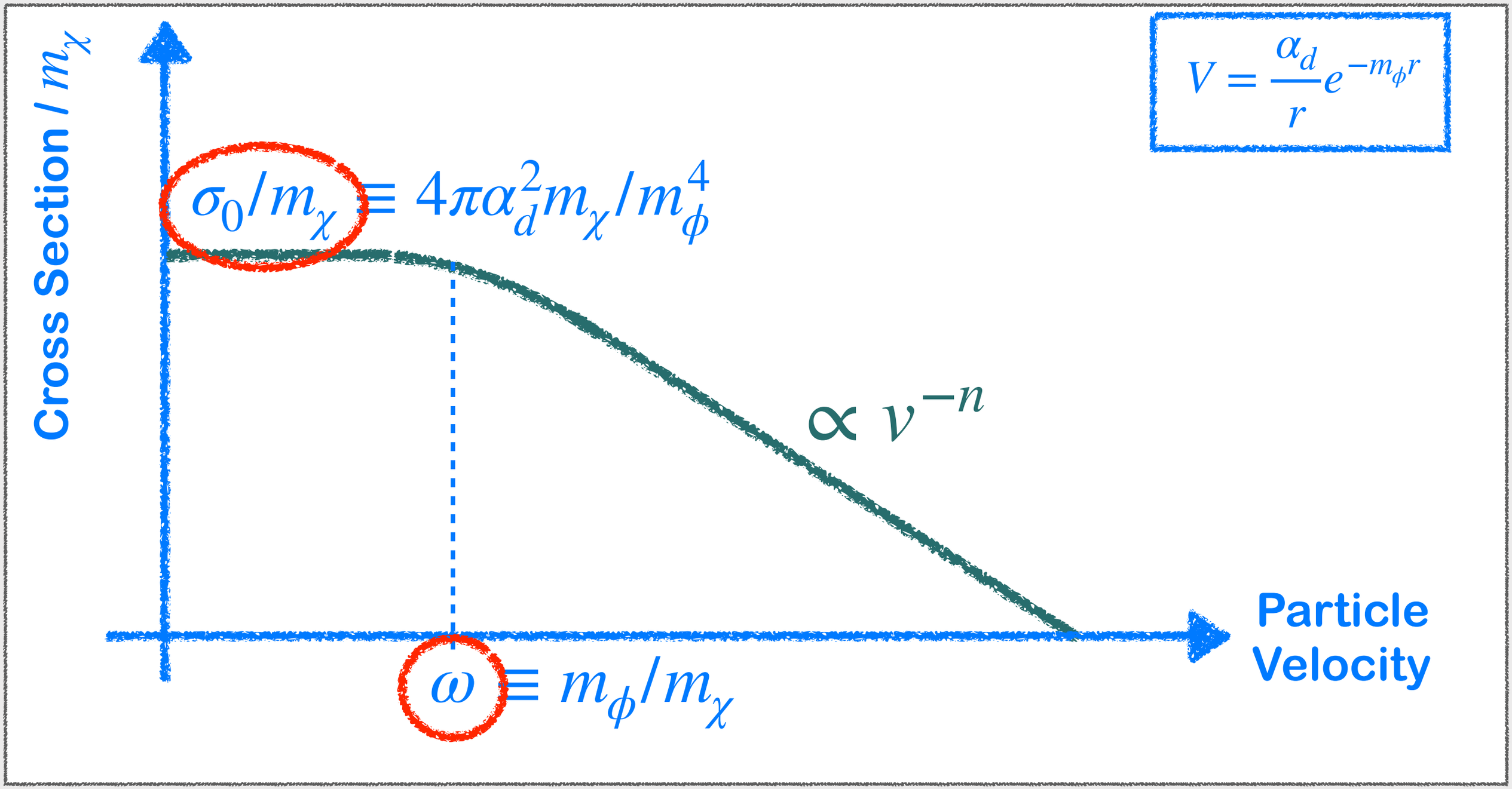




gravitational effects

Compare to astrophysical data and answer fundamental questions

SIDM Cross Section



SIDM Cross Section

Cross Section / m_χ

$10\,\mathrm{cm}^2/\mathrm{g}$ $10^2\,\mathrm{cm}^2/\mathrm{g}$

$1\,\mathrm{cm}^2/\mathrm{g}$

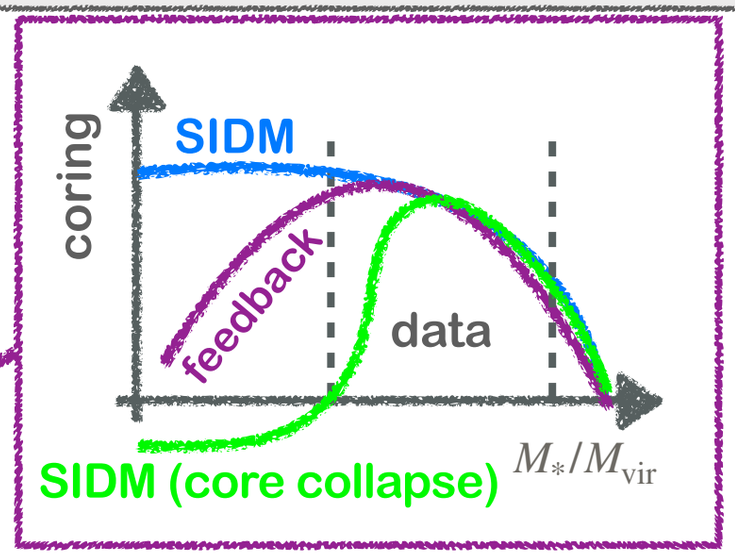
MW Satellites

OS, Jiang, Lisanti, Kaplinghat

Rotation curves
(the standard picture)

Manoj's talk

Bullet-like / groups

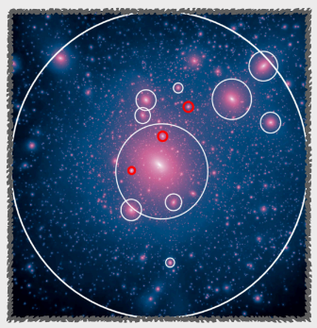


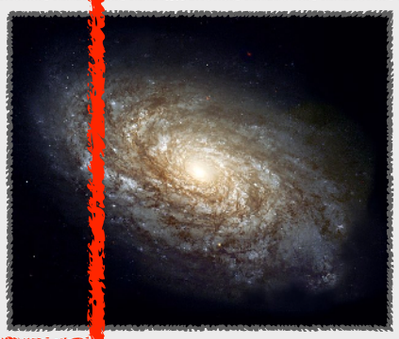
revisited in
Zentner, Dandavate, OS, Lisanti, 2022
small objects can break degeneracy

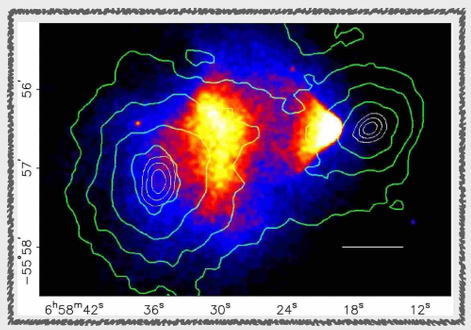
$10\,\mathrm{km/s}$ $10^2\,\mathrm{km/s}$ $10^3\,\mathrm{km/s}$

Particle Velocity

Dwarfs **Galaxies** **Clusters**







Clowe et. al., 2006

Observational consequences of

A self gravitating sphere of SIDM

Dark Sector Kinetic Theory

Is there a fluid description?

Solve for: $\{\rho, T, P, \vec{q}, \vec{u}\}$ (**1.** EOS: $P \propto \rho T$)

Moments of Boltzmann Equation

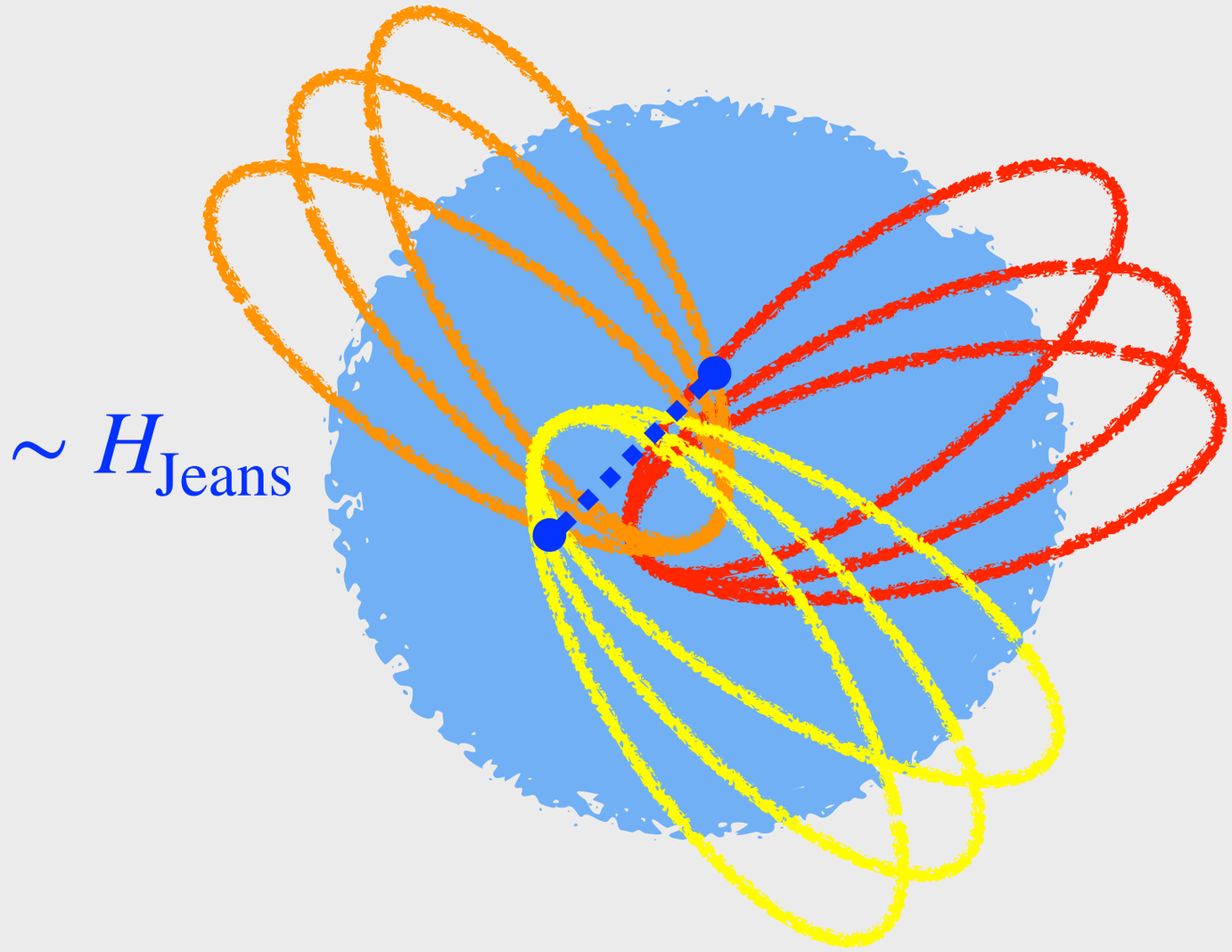
$$\frac{\partial}{\partial t}\langle nA\rangle + \frac{\partial}{\partial \vec{r}}\langle n\vec{v}A\rangle - n\langle \vec{v}\cdot\frac{\partial A}{\partial \vec{r}}\rangle - n\langle \vec{F}\cdot\frac{\partial A}{\partial \vec{p}}\rangle = \int d^3pA\left(\frac{\partial f}{\partial t}\right)_{\text{coll}}$$

2. $A = 1$: **Continuity equation**
3. $A = v$: **Momentum conservation**
4. $A = v^2$: **Energy conservation**

Heat flux

5. $\vec{q} = \kappa \cdot \vec{\nabla} T$ (when $\lambda_{\text{MFP}} \ll H_{\text{Jeans}} \rightarrow \kappa \propto \lambda_{\text{MFP}} v$)

SIDM and Kinetic Theory



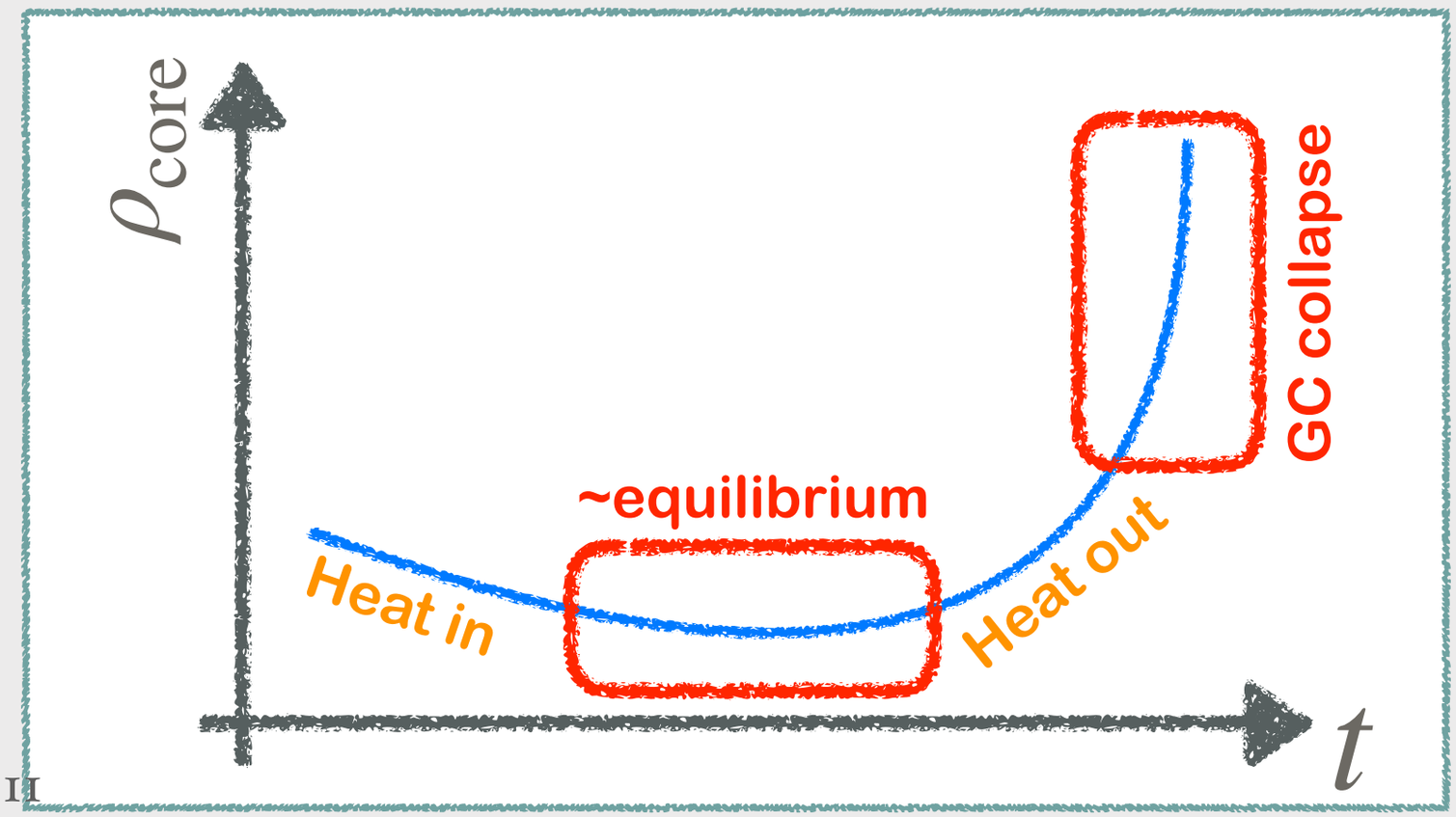
Heat flux when $\lambda_{\rm MFP} > H_{\rm Jeans}$:

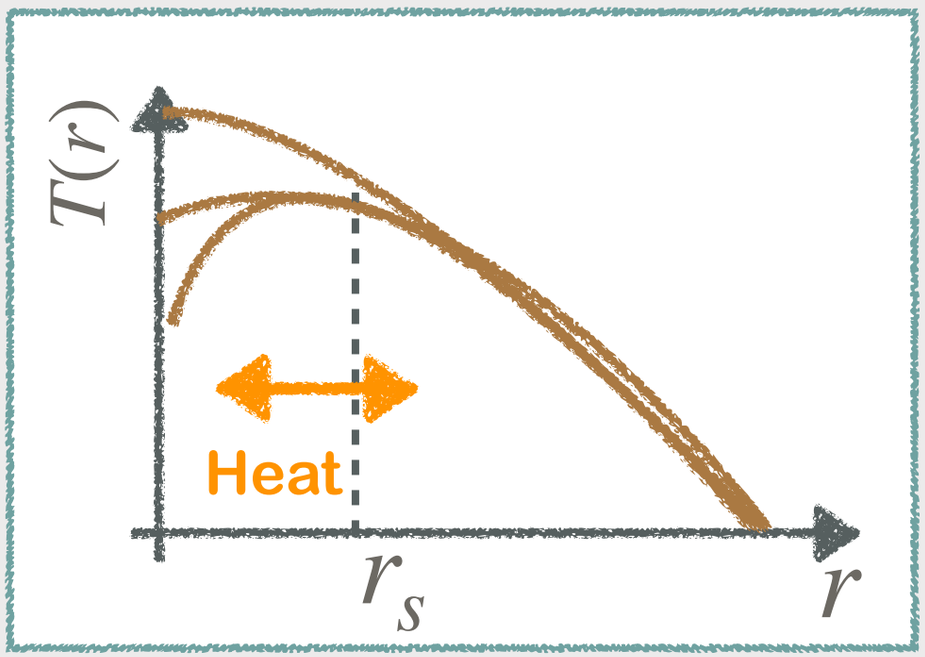
$$\kappa \propto \lambda_{\rm MFP} \times v \approx H_{\rm Jeans} \times H_{\rm Jeans}/t_{\rm coll}$$

SIDM Dynamics

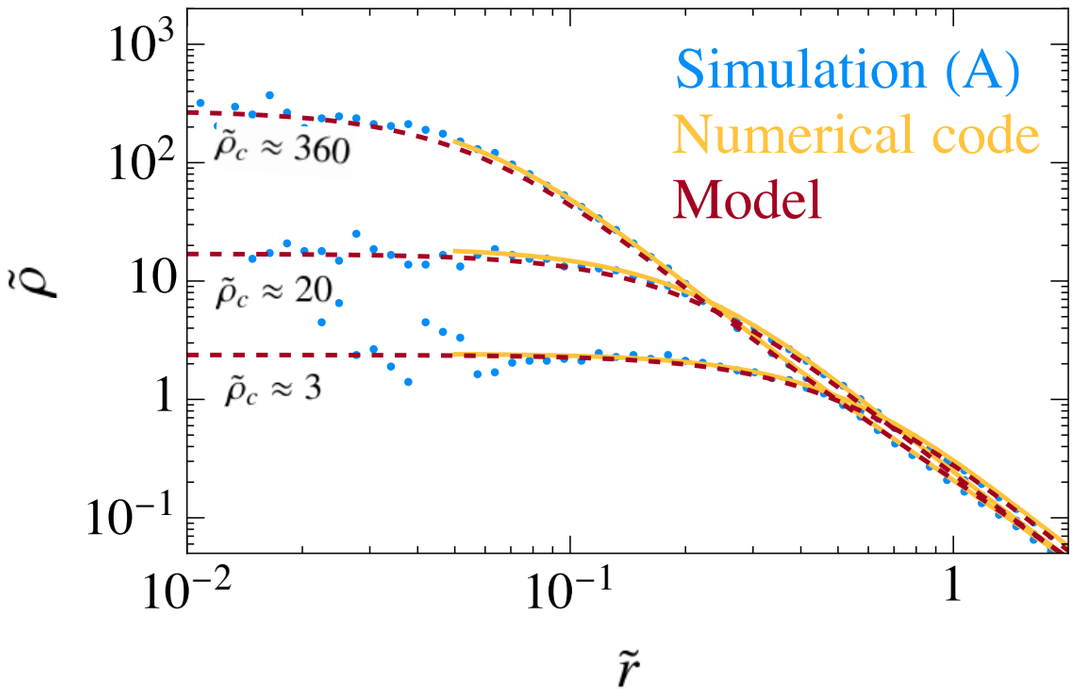
1. Equation of state
2. Continuity equation
3. Momentum conservation
4. Energy conservation
5. Heat flux equation

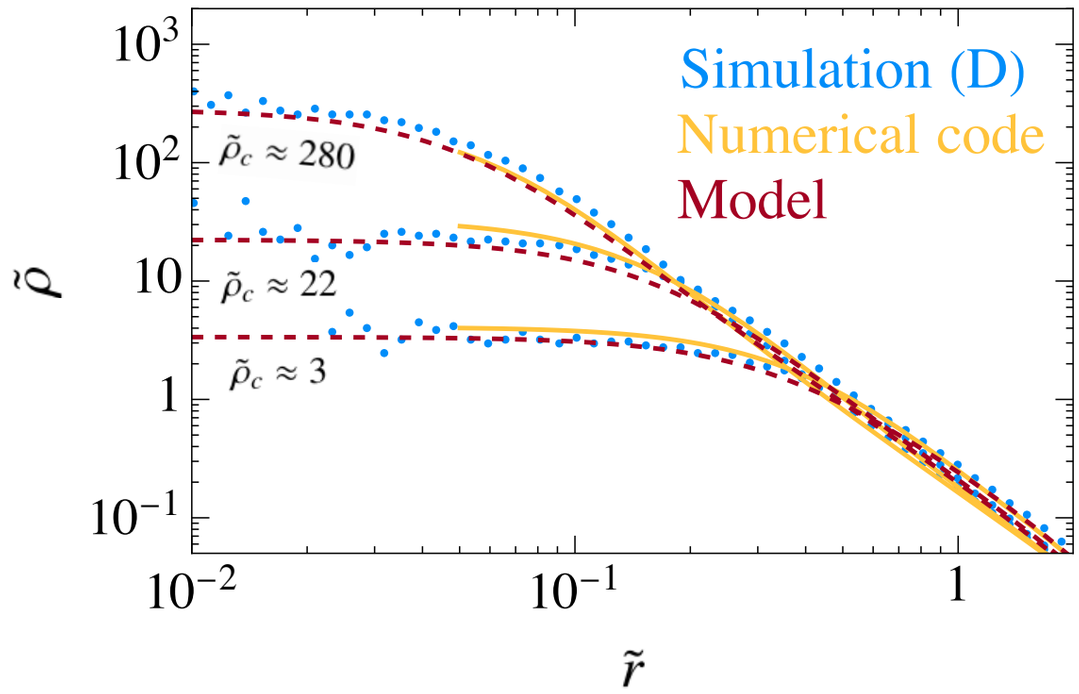
$$\Big\} \rightarrow \{\rho, T, P, \vec{q}, \vec{u}\}$$

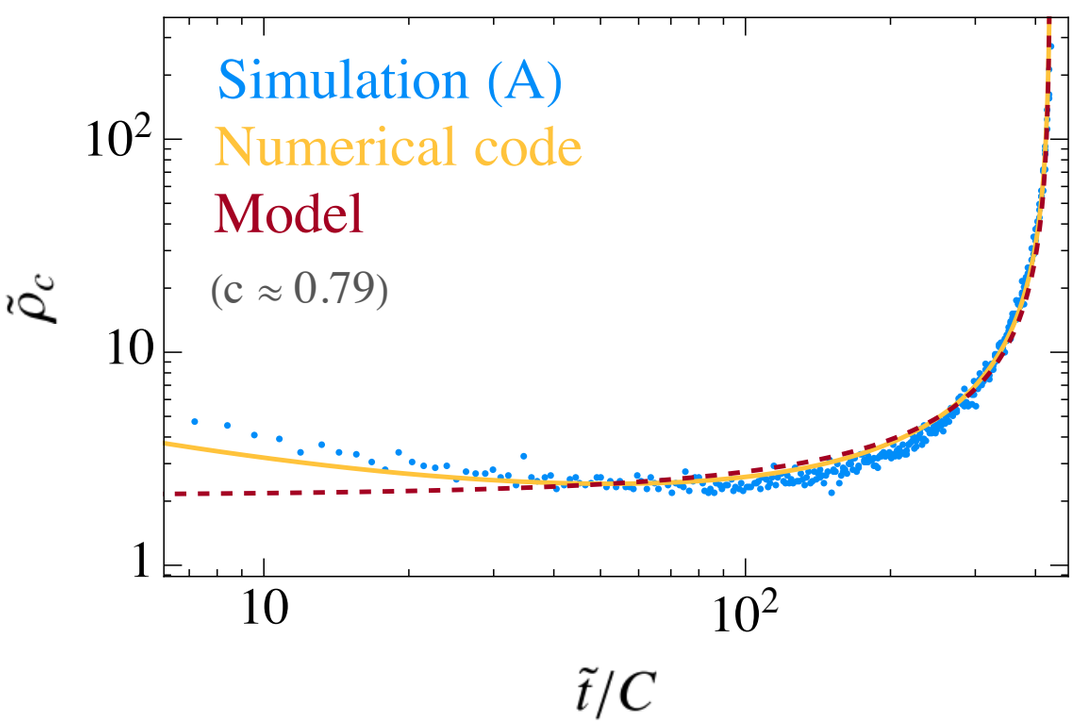


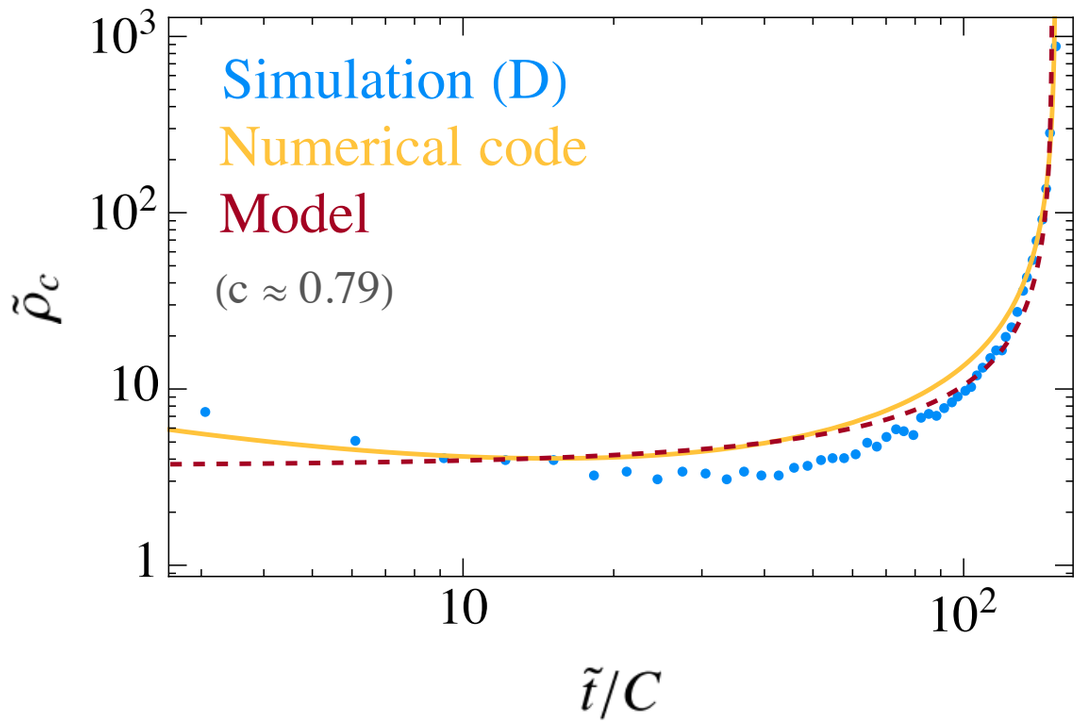


Fits simulations







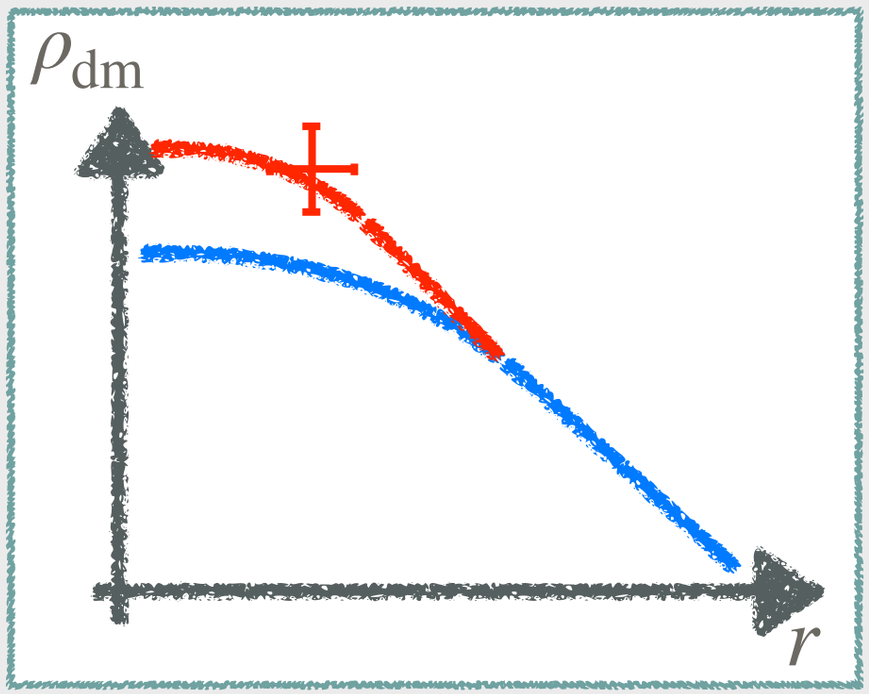


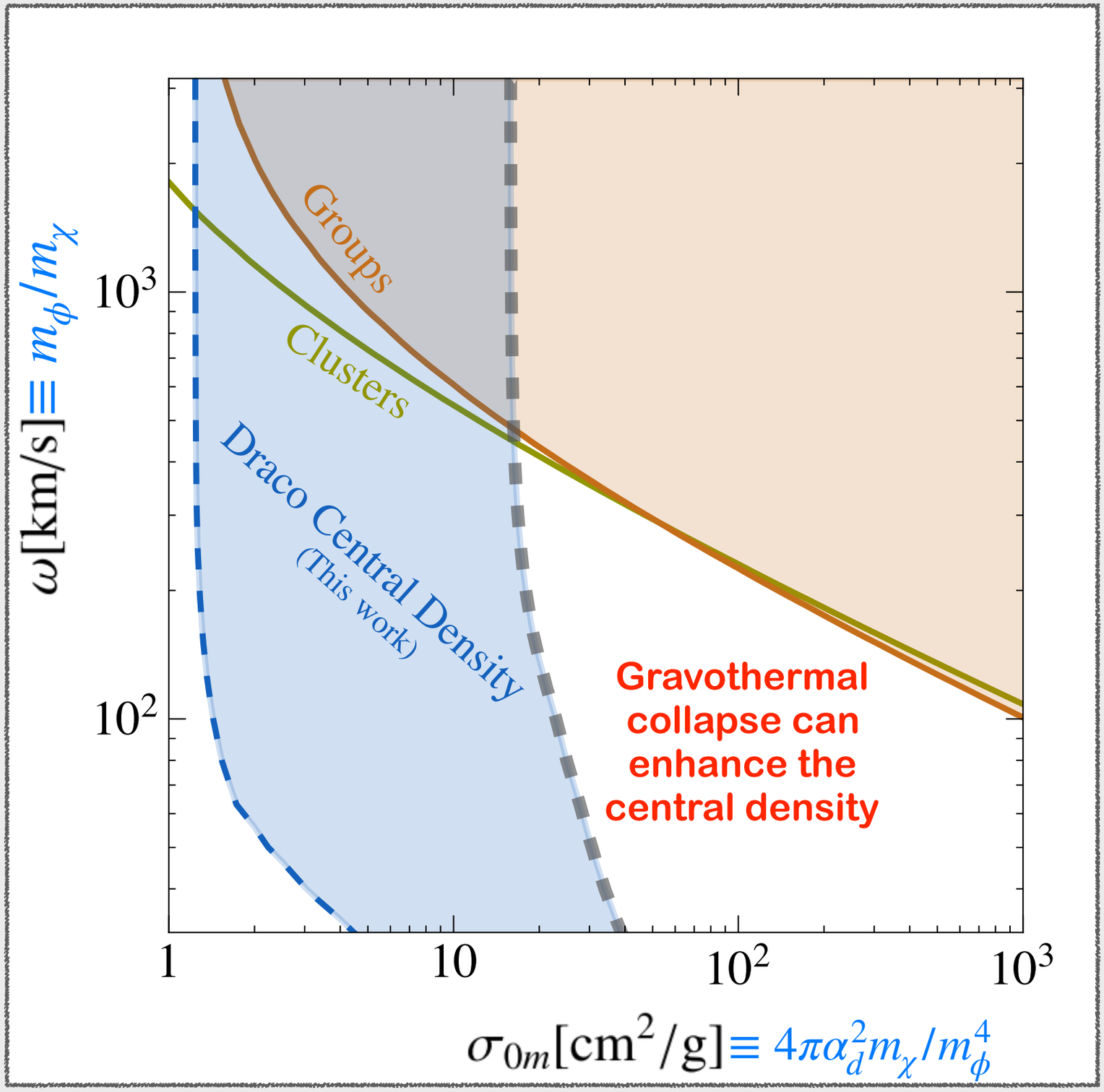
OS, Jiang, Palubski, Lisanti & Kaplinghat, *PRELIMINARY*

Bounds from Dwarfs

Draco's measured average central density:

$$\rho_{150} = 0.212 \pm 0.045\, M_\odot/\mathrm{pc}^3$$





OS, Jiang, Lisanti & Kaplinghat

SIDM Cross Section

$$V = \frac{\alpha_d}{r} e^{-m_\phi r}$$

Cross Section / m_χ

$10\,\mathrm{cm}^2/\mathrm{g}$

$10^2\,\mathrm{cm}^2/\mathrm{g}$

$1\,\mathrm{cm}^2/\mathrm{g}$

Small halos collapsing

OS, Jiang, Lisanti, Kaplinghat

Strongly Self-Interacting

Weakly Self-Interacting (CDM)

$10\,\mathrm{km/s}$

$10^2\,\mathrm{km/s}$

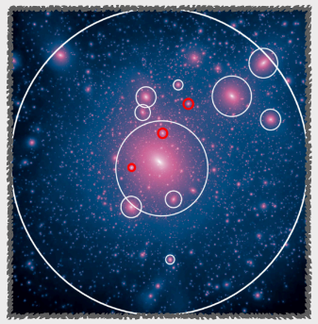
$10^3\,\mathrm{km/s}$

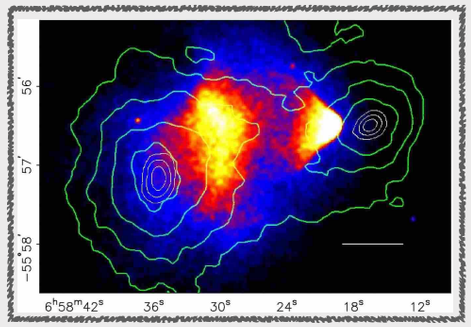
Particle Velocity

Dwarfs

Galaxies

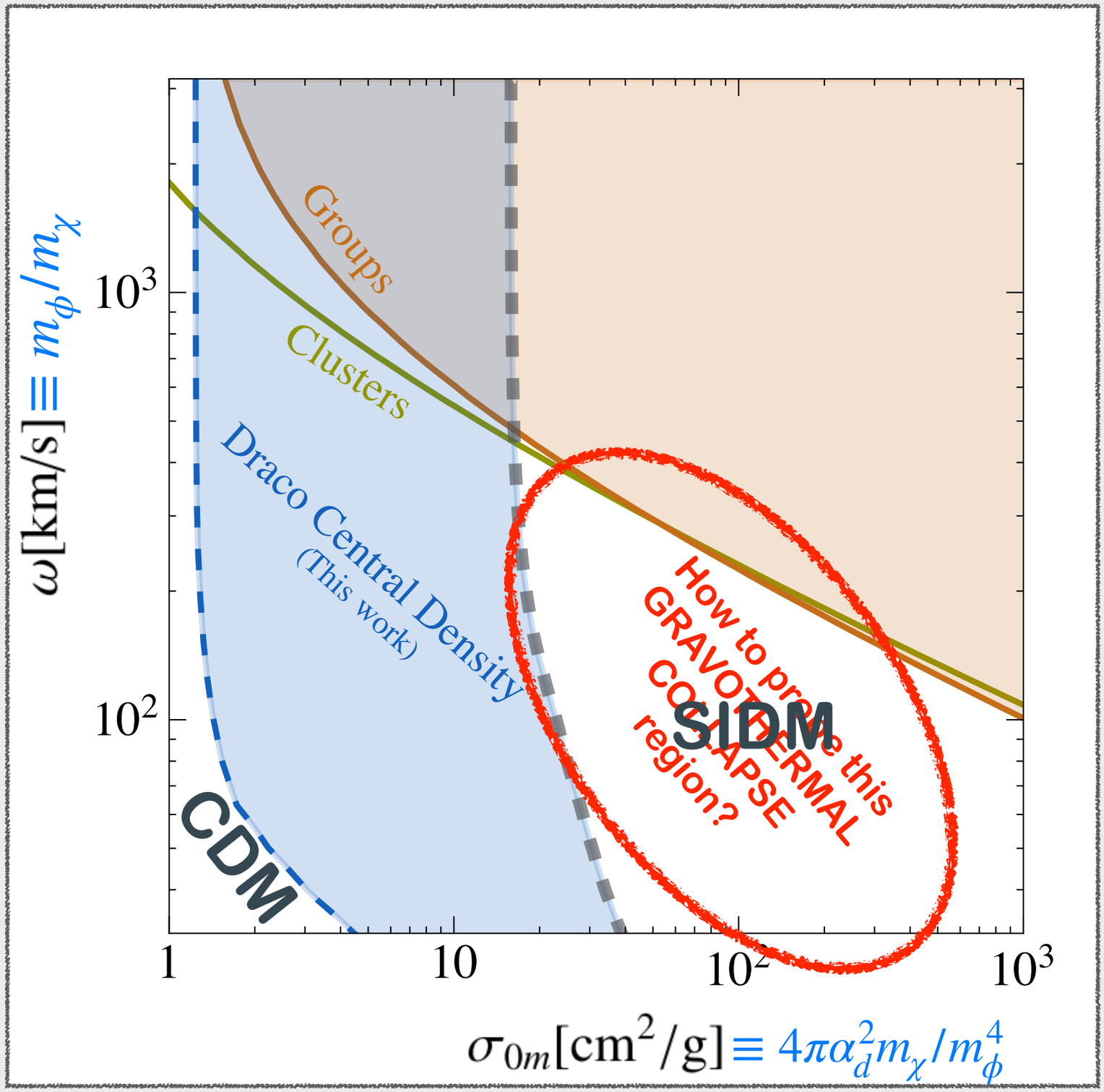
Clusters





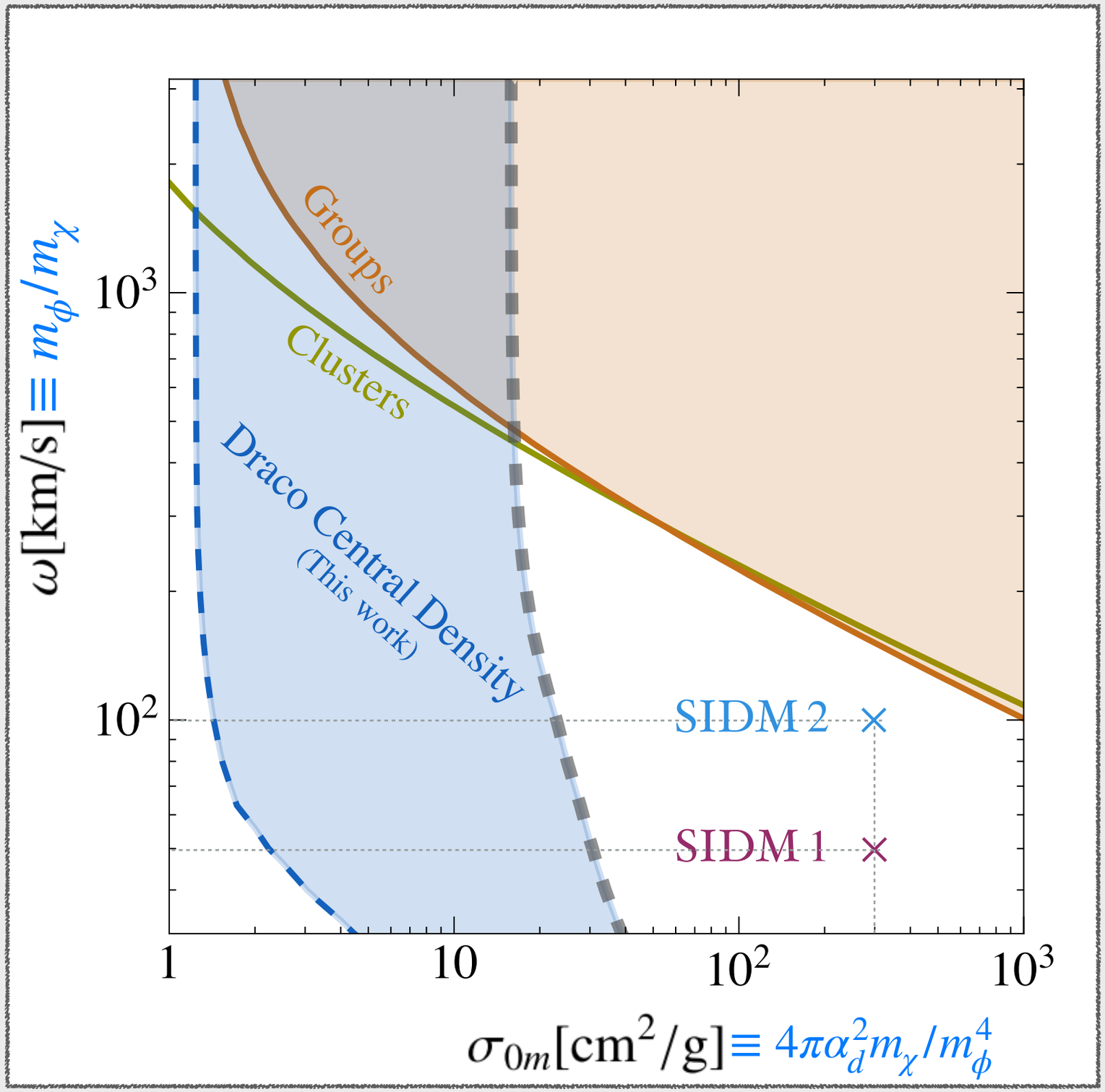
Clowe et. al., 2006

Some SIDM halos must Gravothermally Collapse



OS, Jiang, Lisanti & Kaplinghat

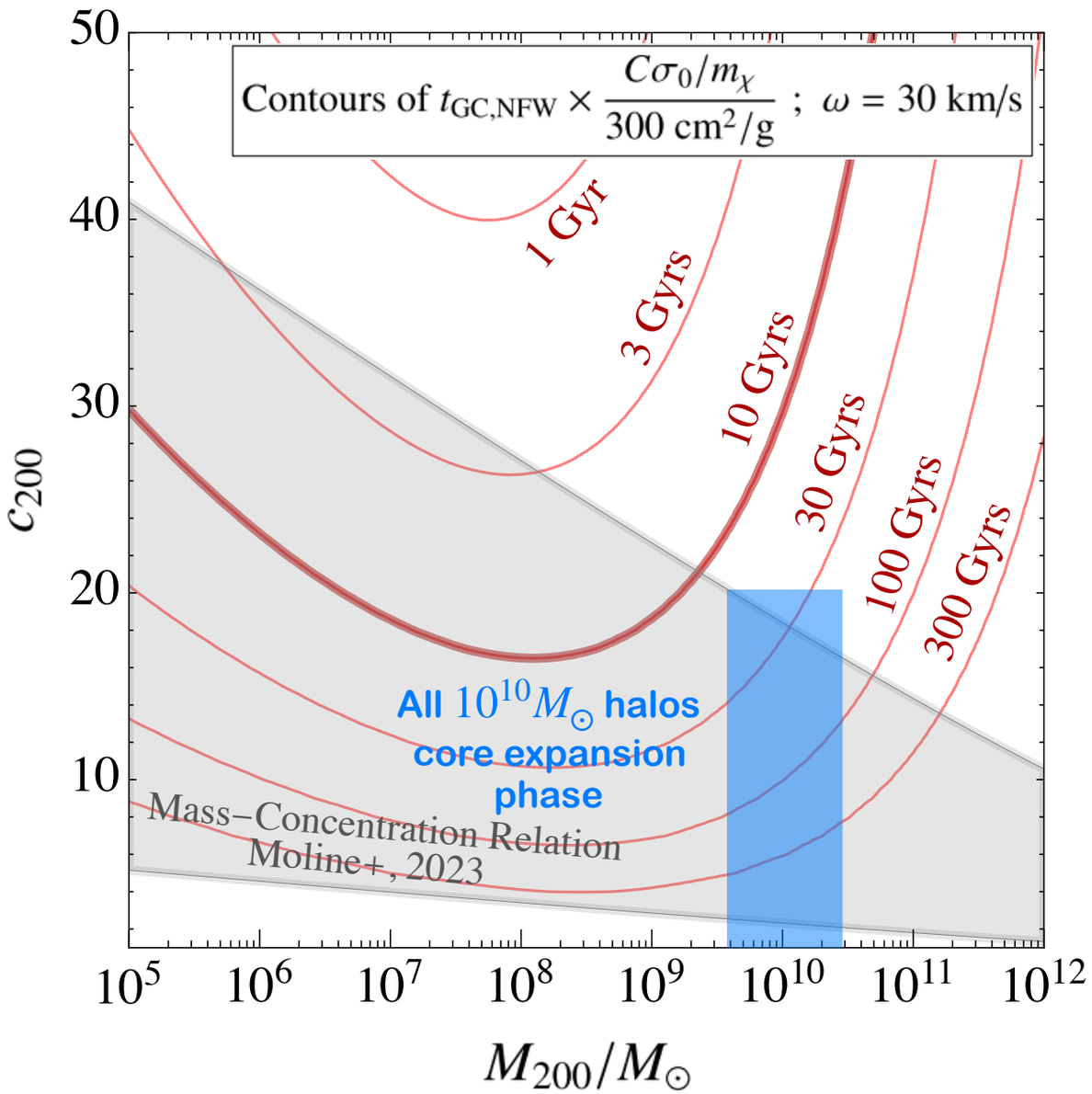
Exploring Allowed Parameter Space



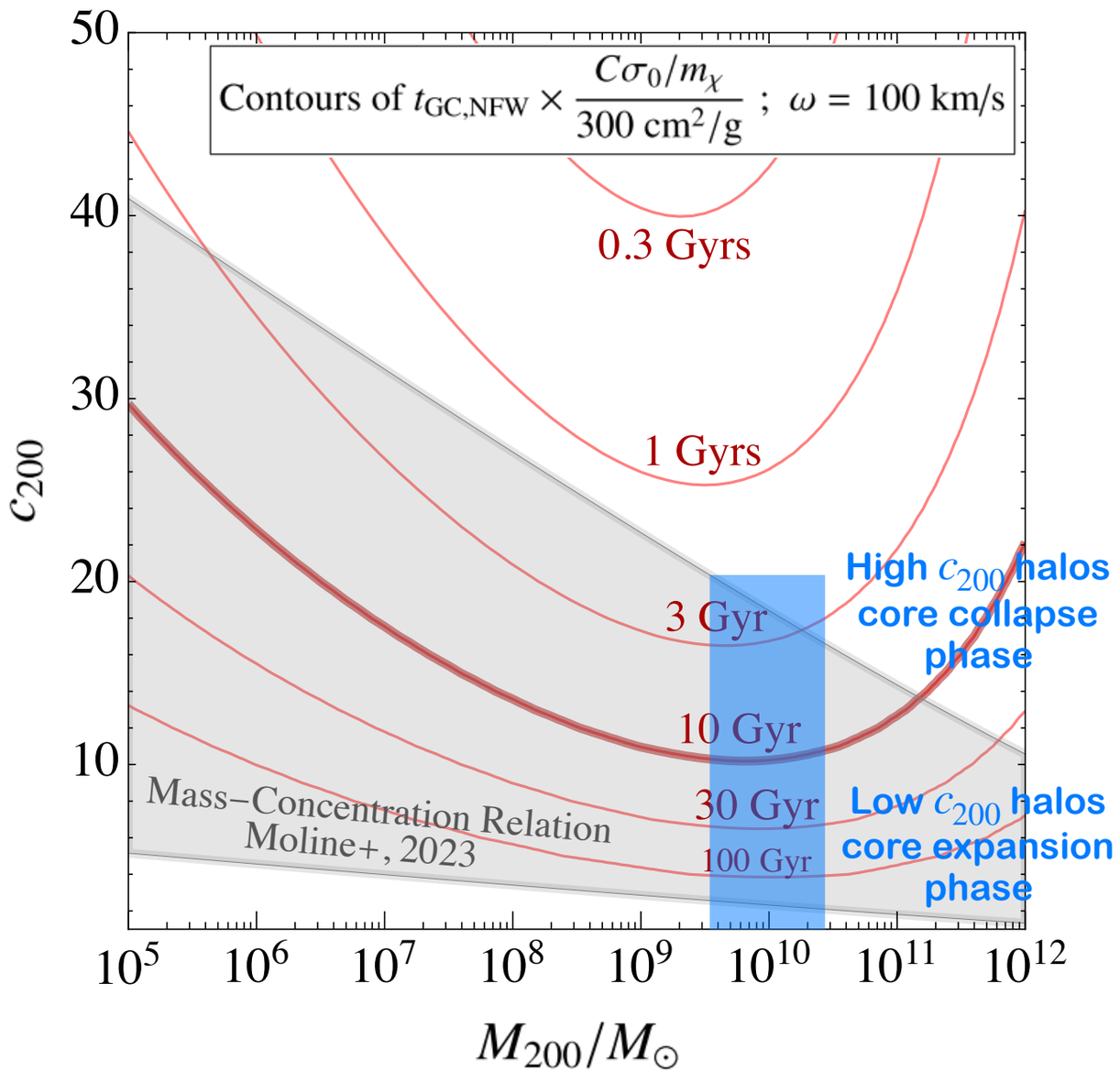
OS, Jiang, Lisanti & Kaplinghat, 2021

Gravothermal Collapse Timescale

SIDM 1

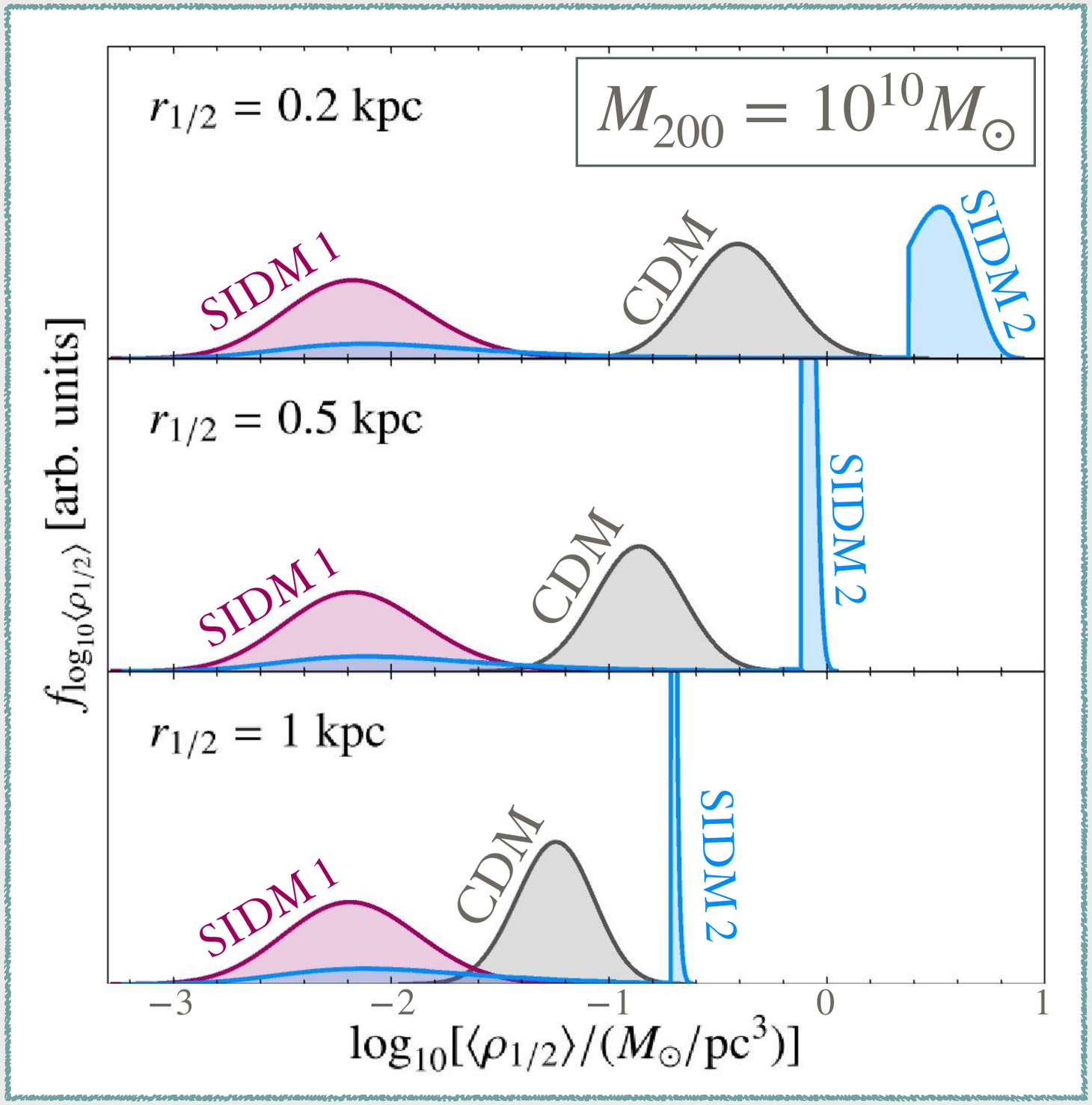


SIDM 2



OS, Jiang, Palubski, Lisanti & Kaplinghat, *PRELIMINARY*

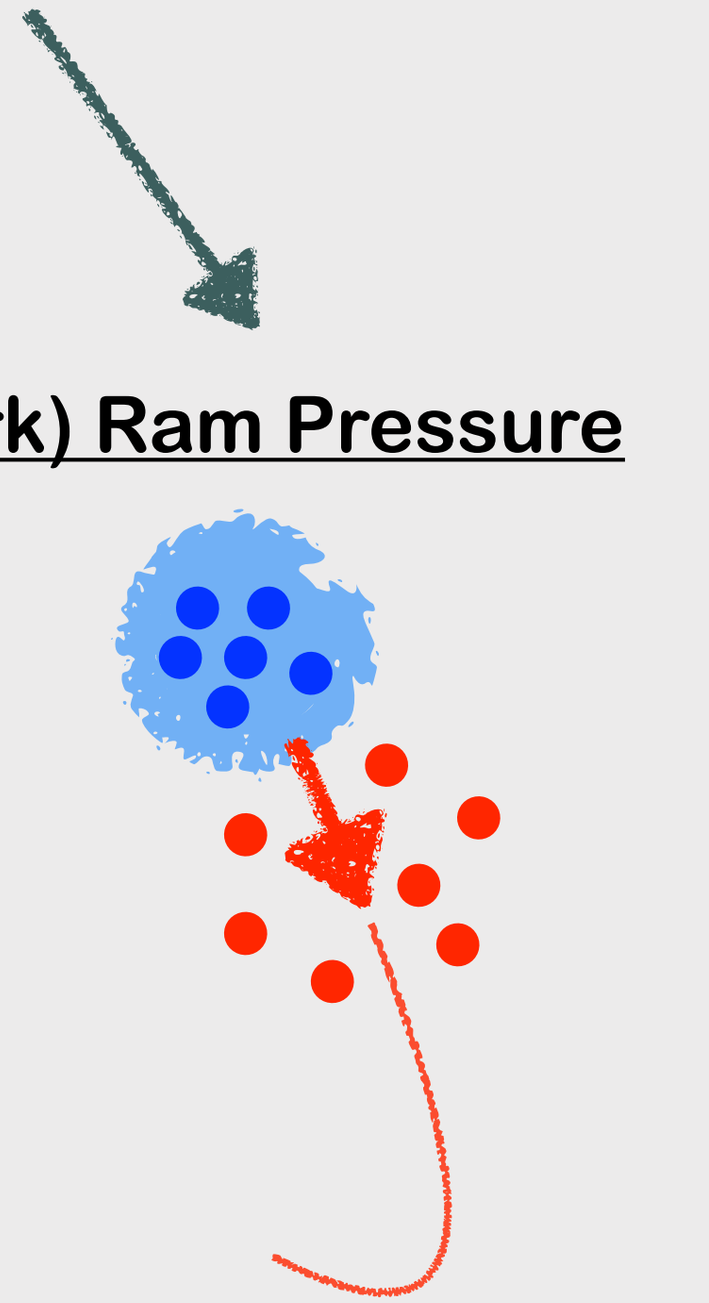
A Smoking-Gun Signal



OS, Jiang, Palubski, Lisanti & Kaplinghat, PRELIMINARY

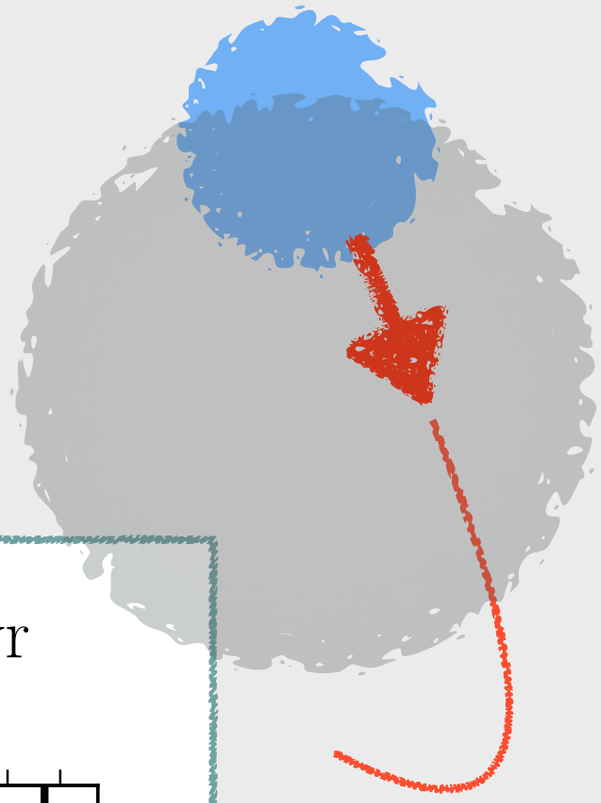
SIDM Dwarf Galaxies in Real Environments

Tidal Stripping

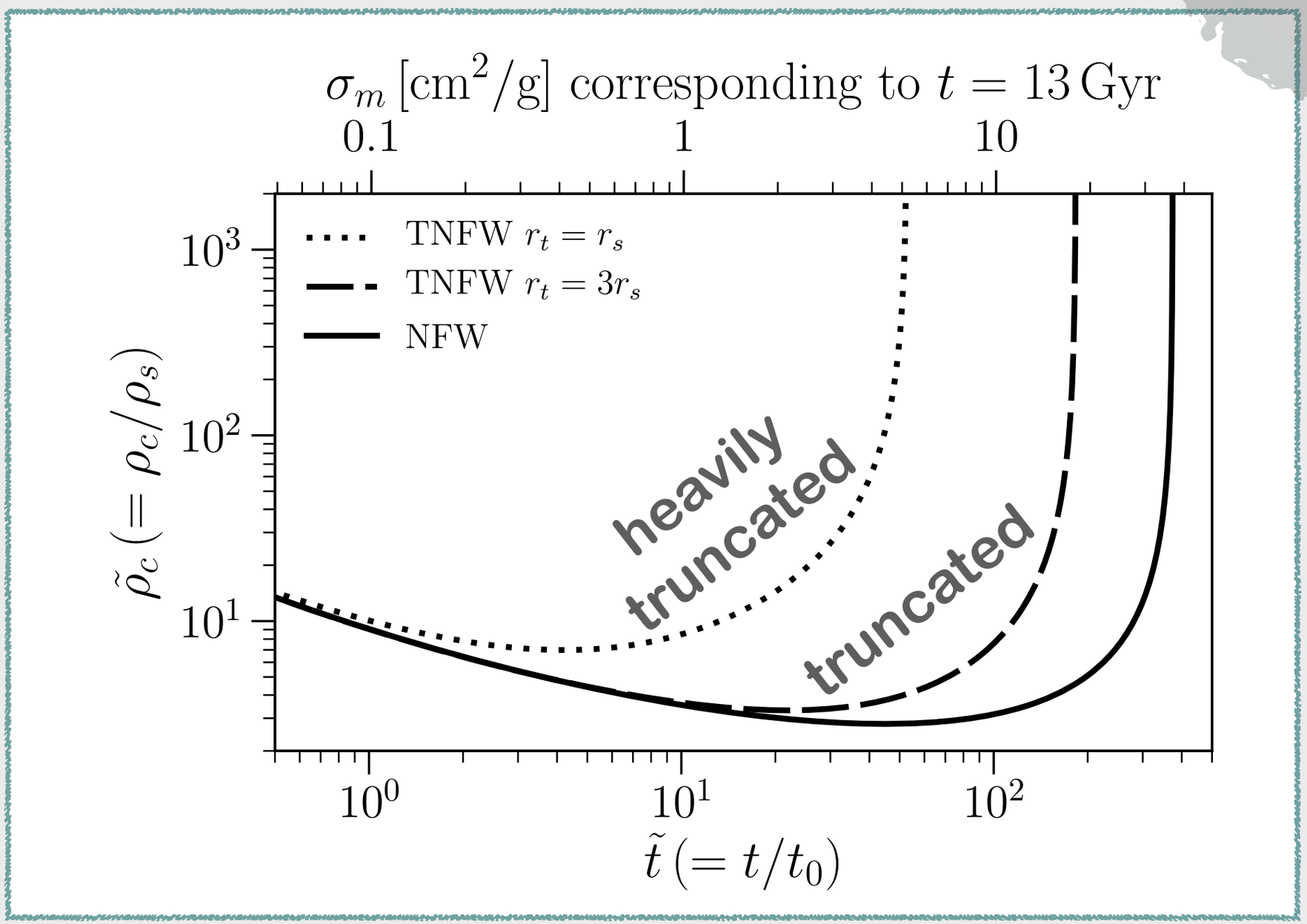


(Dark) Ram Pressure

Tidal Stripping

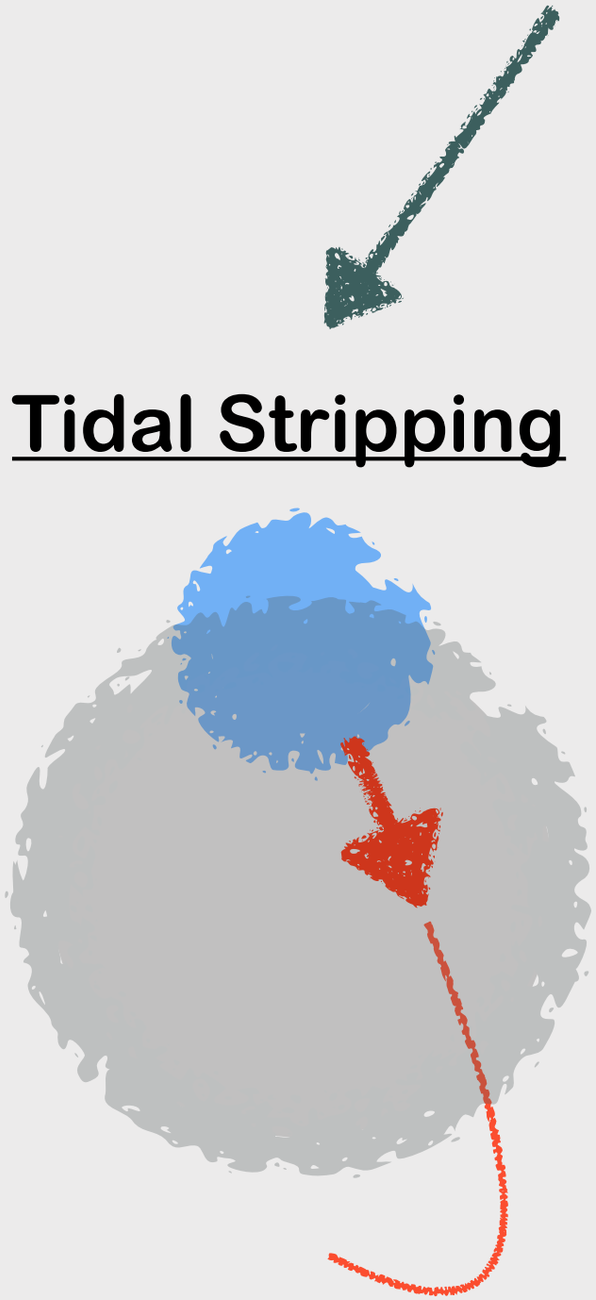


Accelerates Core Collapse

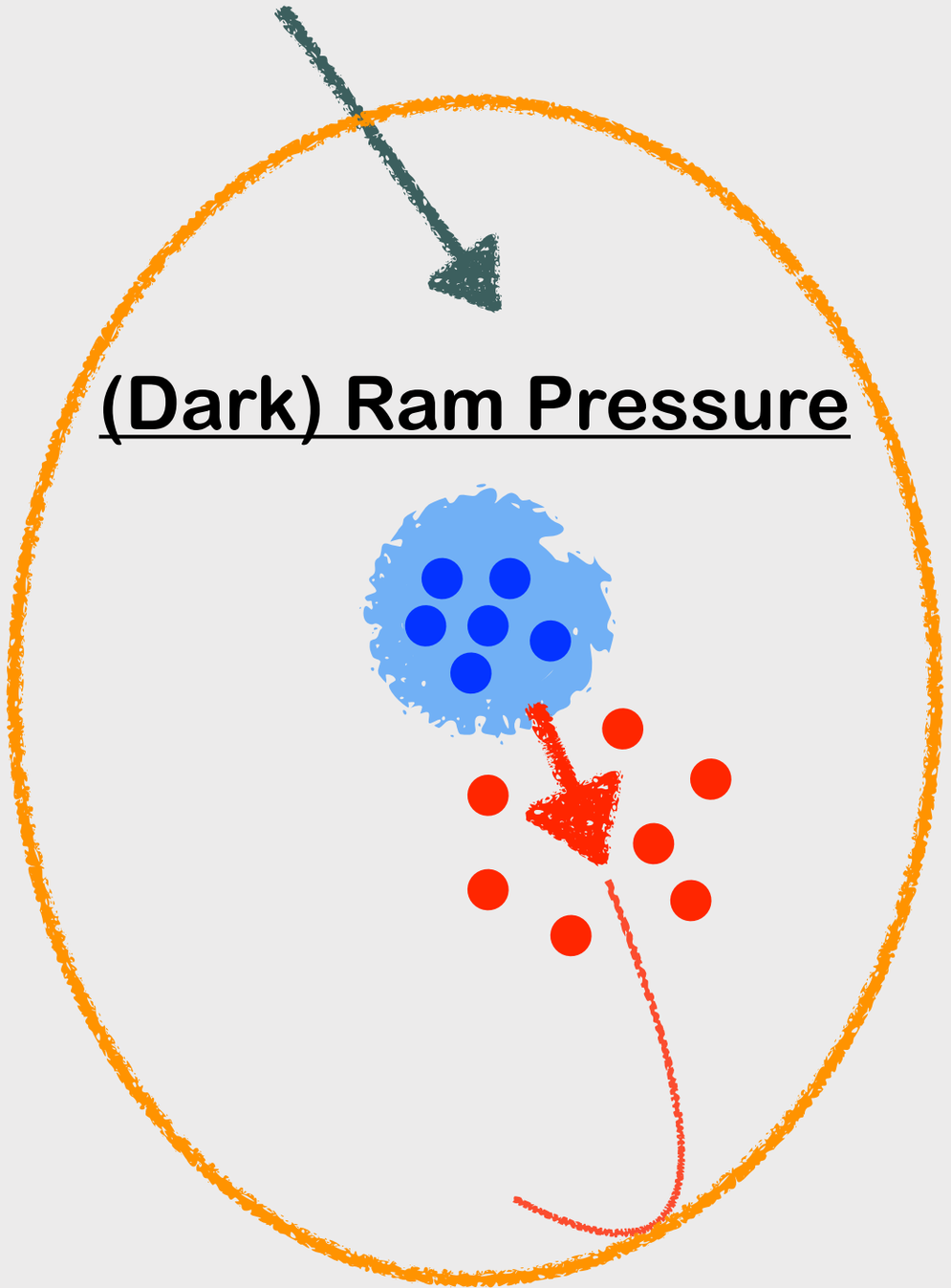


Nishikawa et. al., 2020

SIDM Dwarf Galaxies in Real Environments



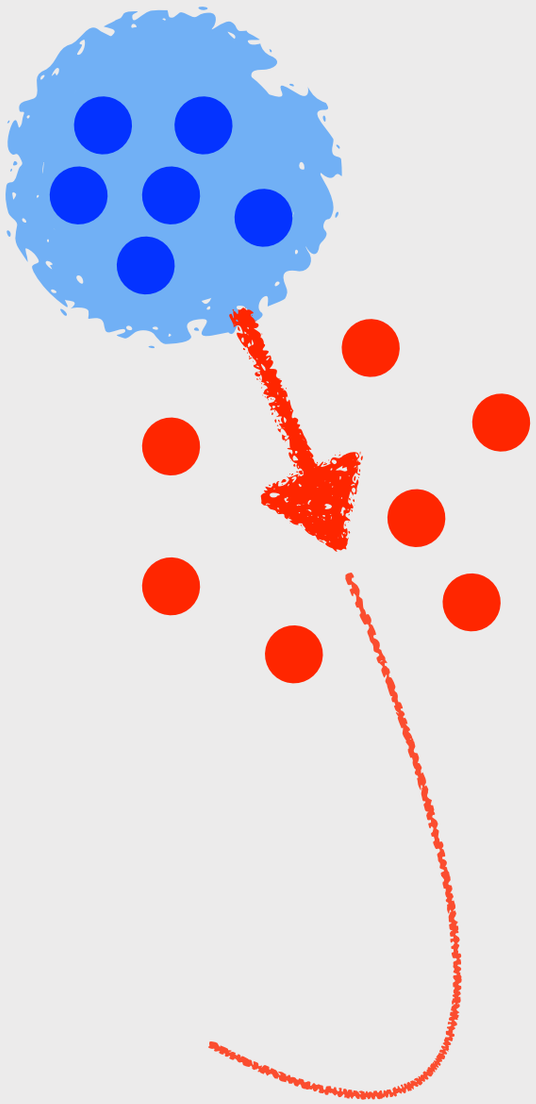
Tidal Stripping

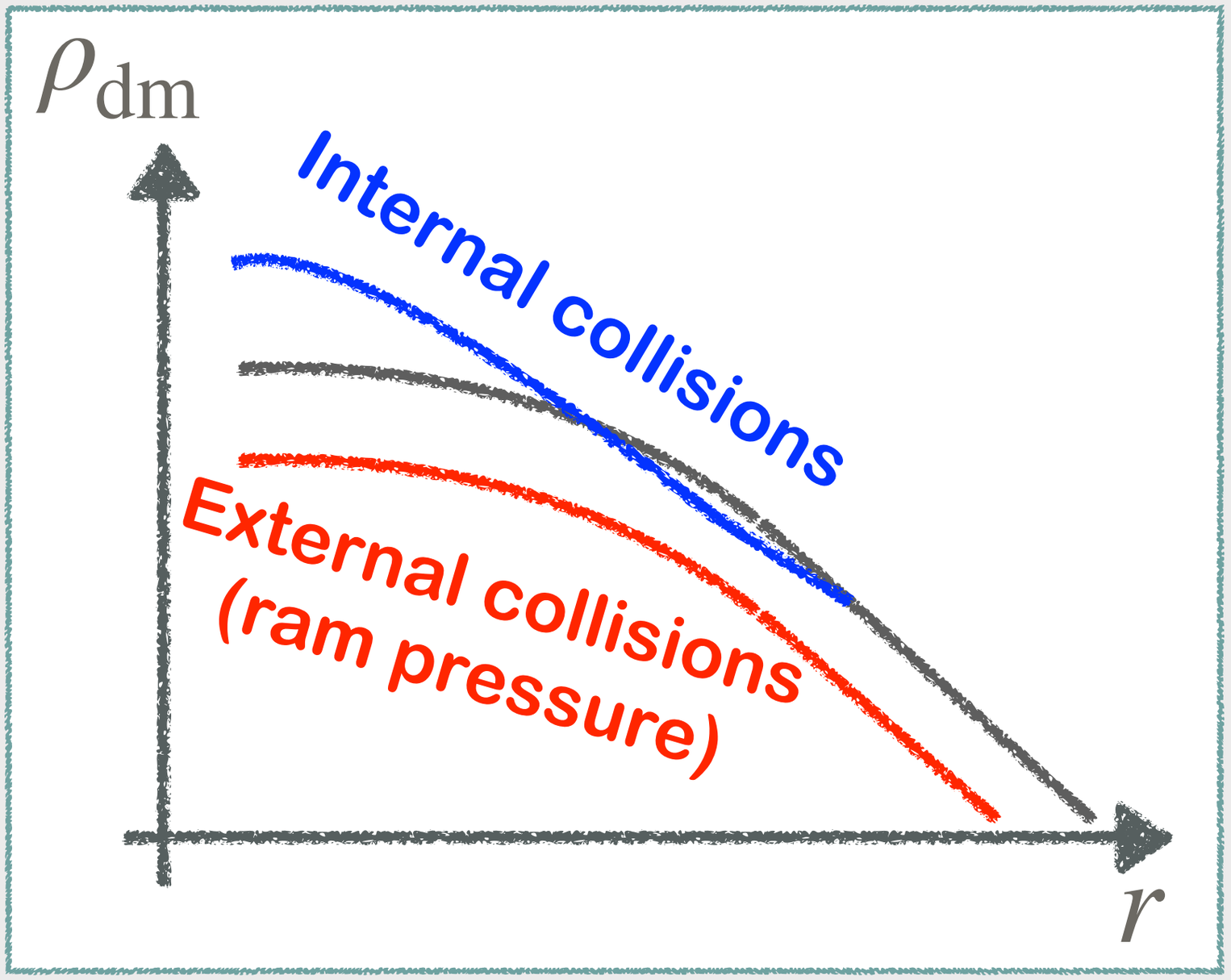


(Dark) Ram Pressure

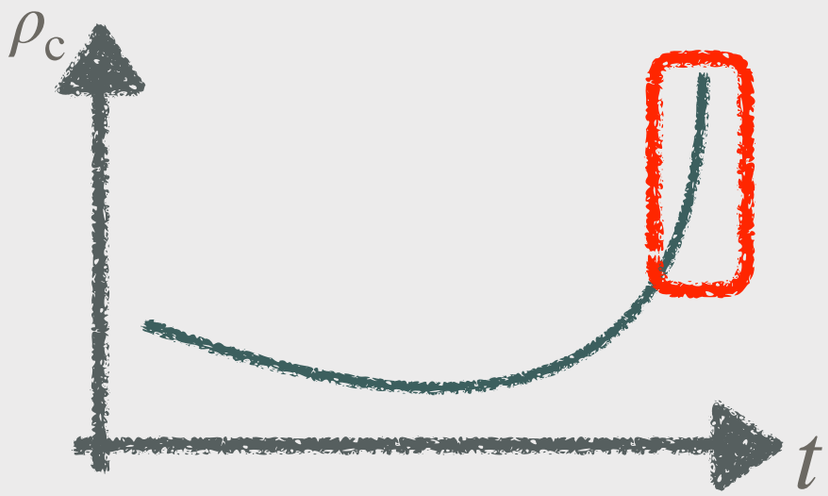
Dark Matter Ram Pressure

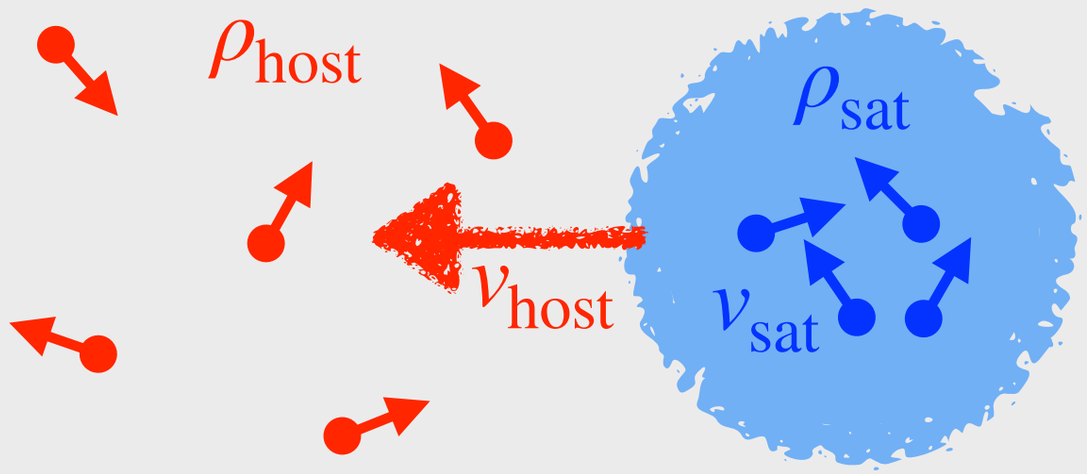
Suppresses Core Collapse





Which rates control which process?





Controlled by
heat transfer rate

$$\Gamma_{\rm sat} \sim \rho_{\rm sat} \langle \sigma v \rangle_{\rm sat} / m_\chi$$

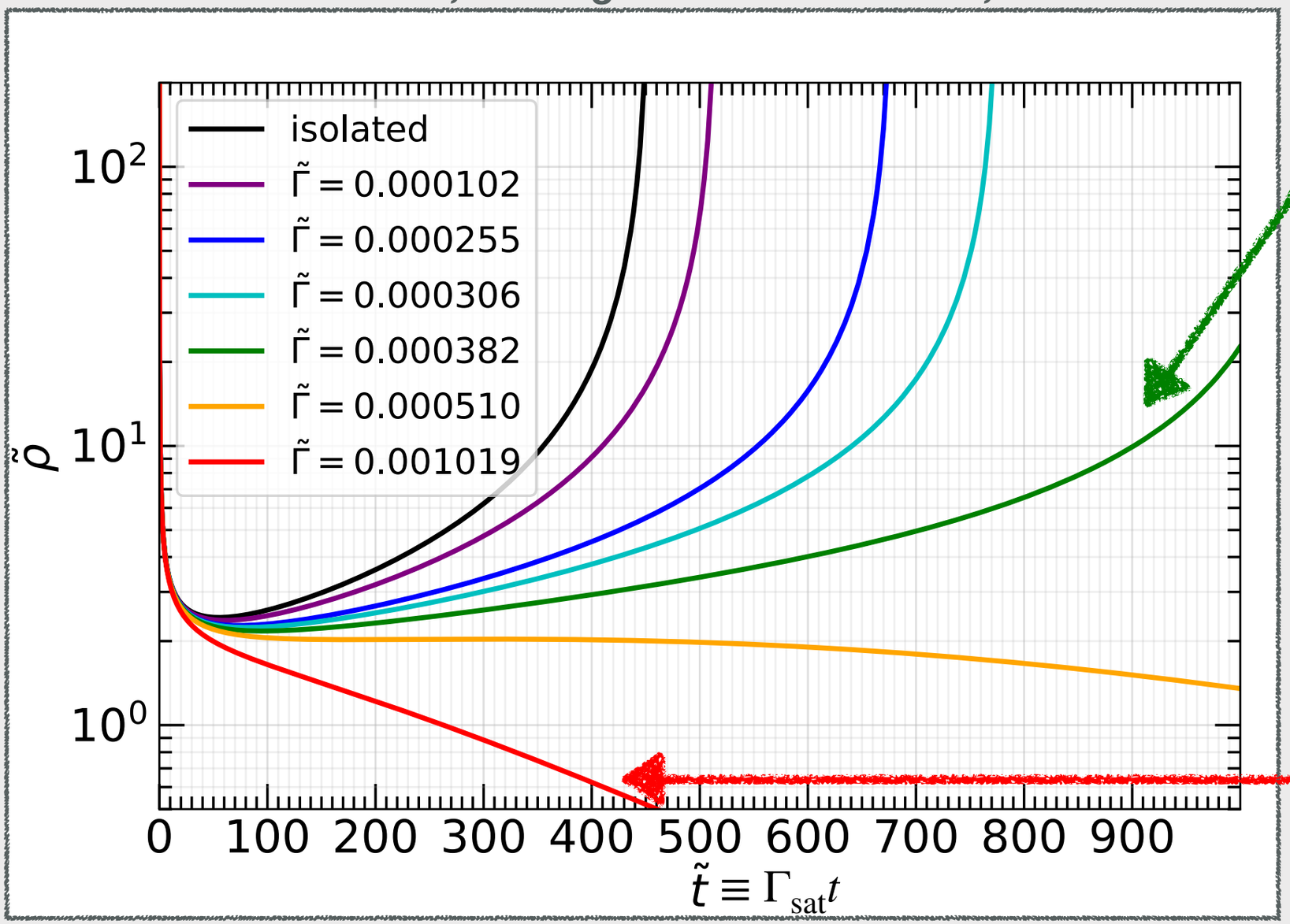
Controlled by
evaporation rate

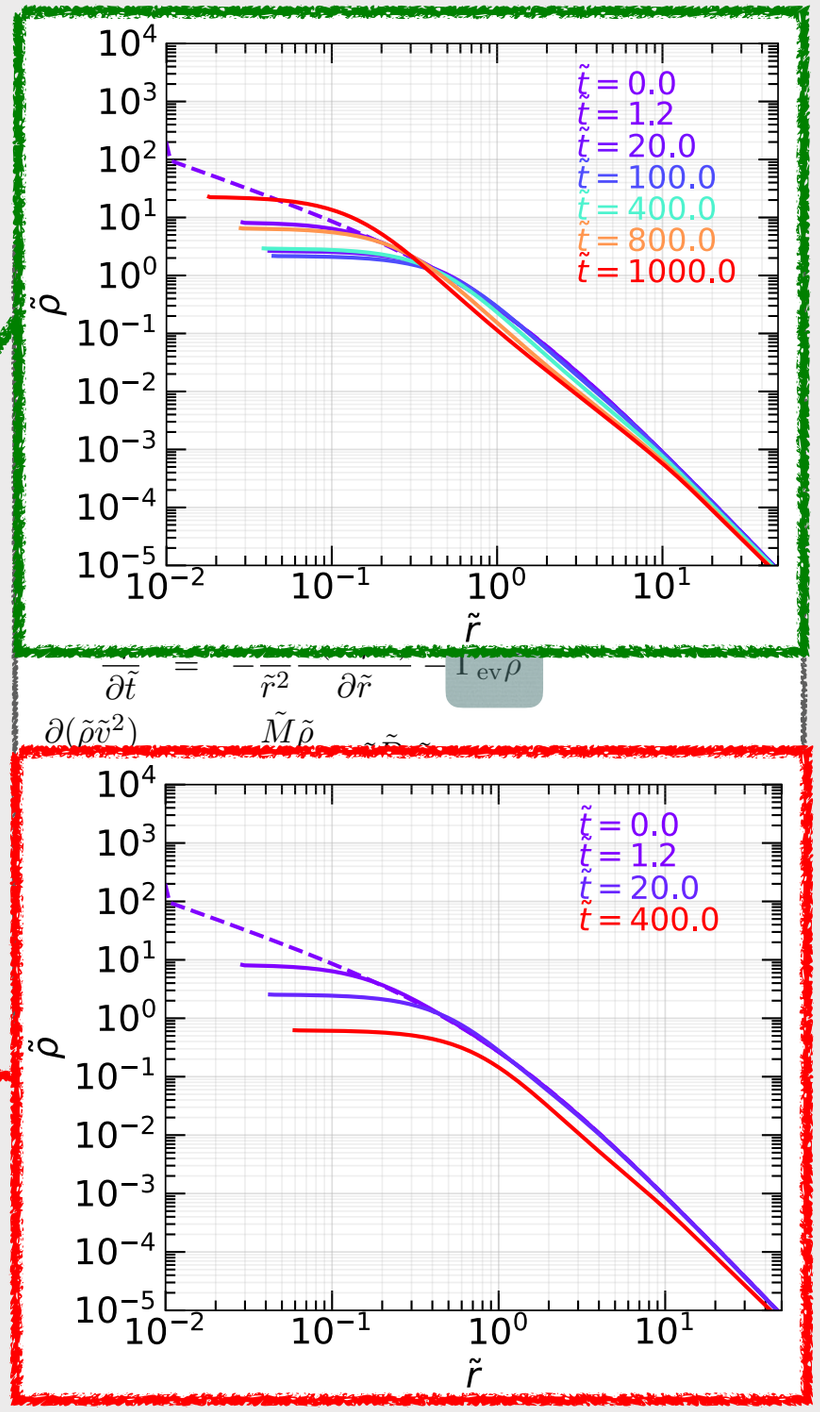
$$\Gamma_{\rm ev} \sim \rho_{\rm host} \langle \sigma v \rangle_{\rm host} / m_\chi$$

Compete with each other

New Fluid Equations

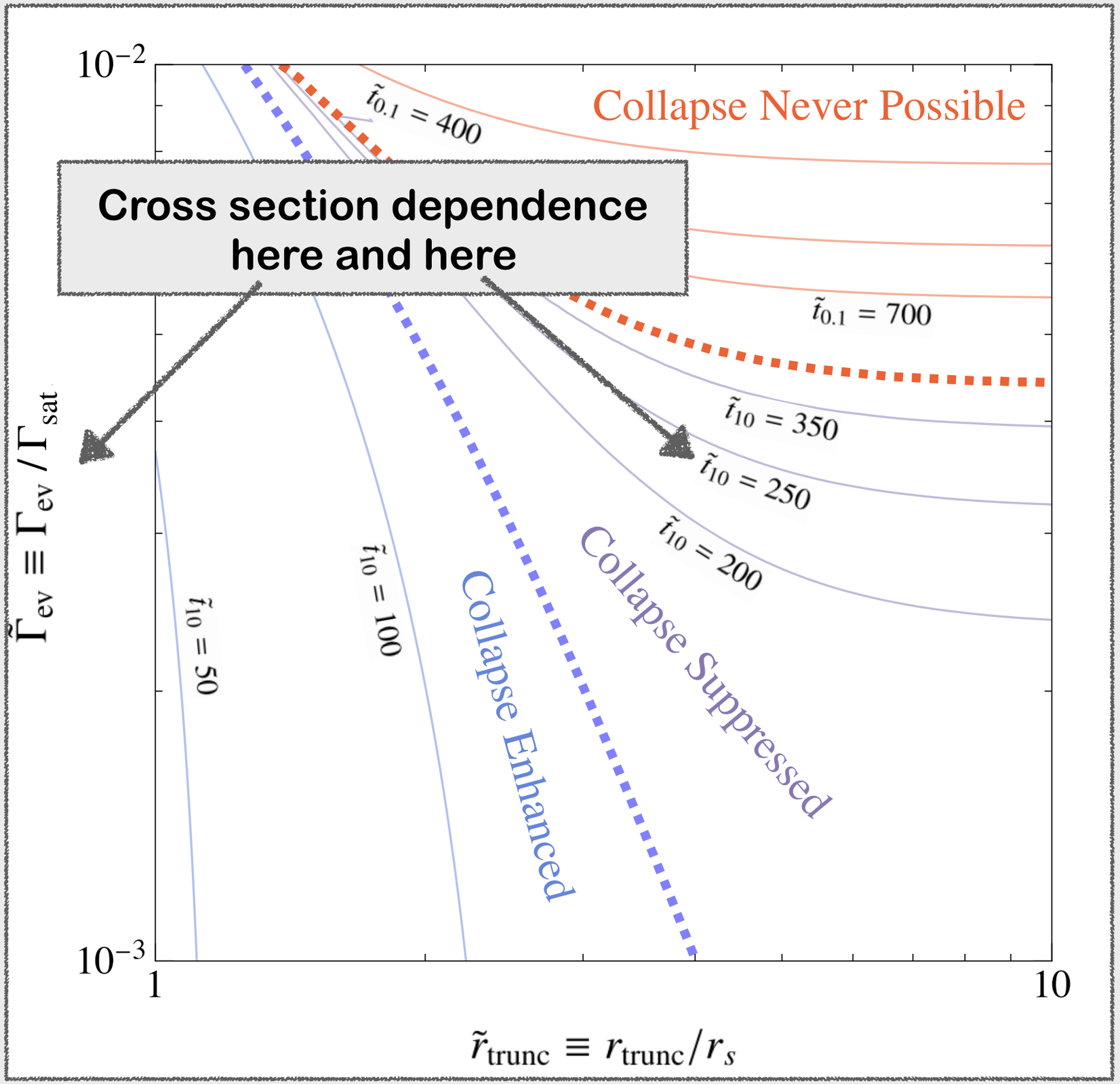
OS, F. Jiang & F. van den Bosch, PRELIMINARY





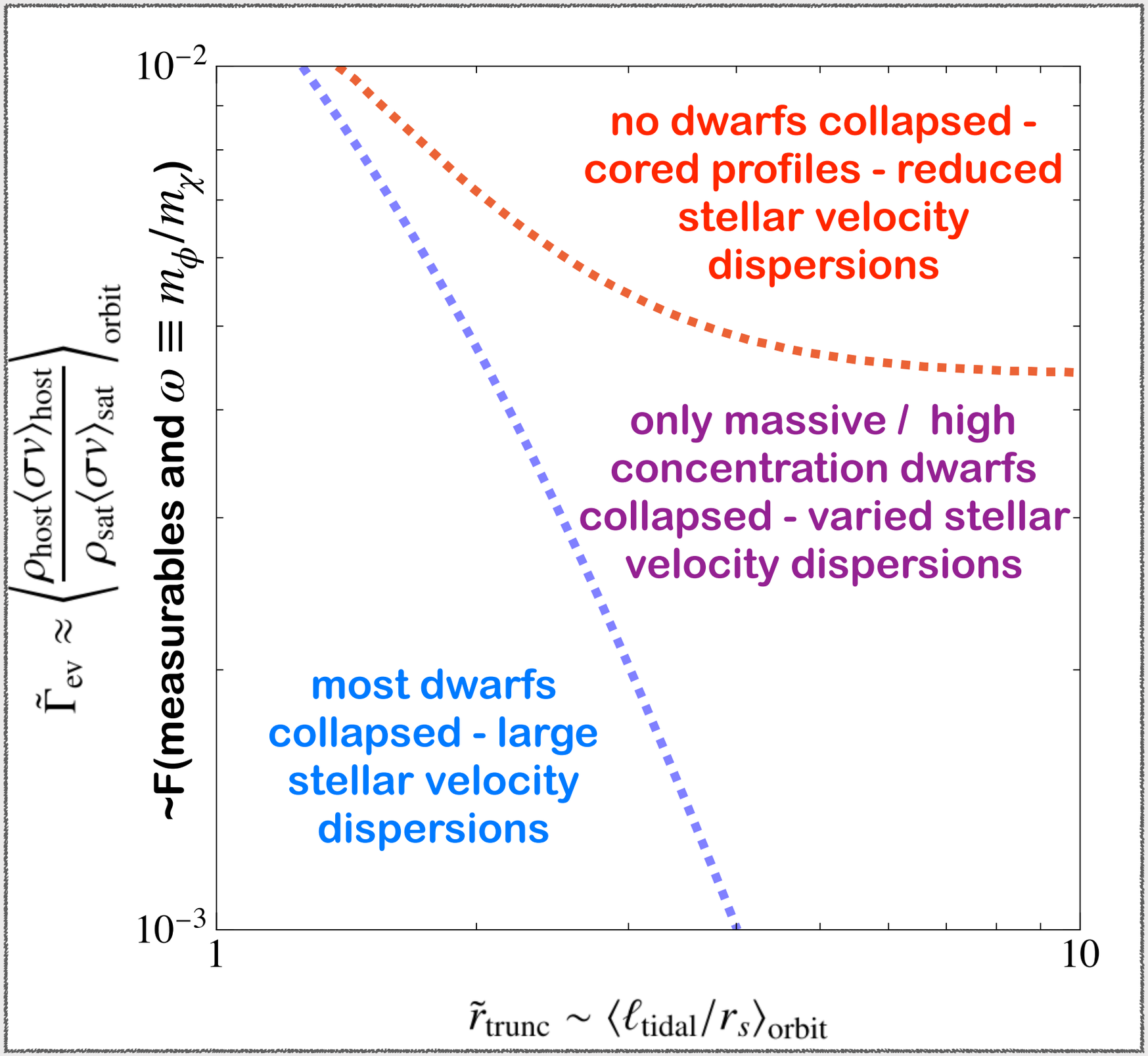
$$\tilde{\Gamma}_{\rm ev} \equiv \Gamma_{\rm ev}/\Gamma_{\rm sat} \approx \frac{\rho_{\rm host}\langle\sigma v\rangle_{\rm host}}{\rho_{\rm sat}\langle\sigma v\rangle_{\rm sat}}$$

Ram Pressure + Tidal Stripping



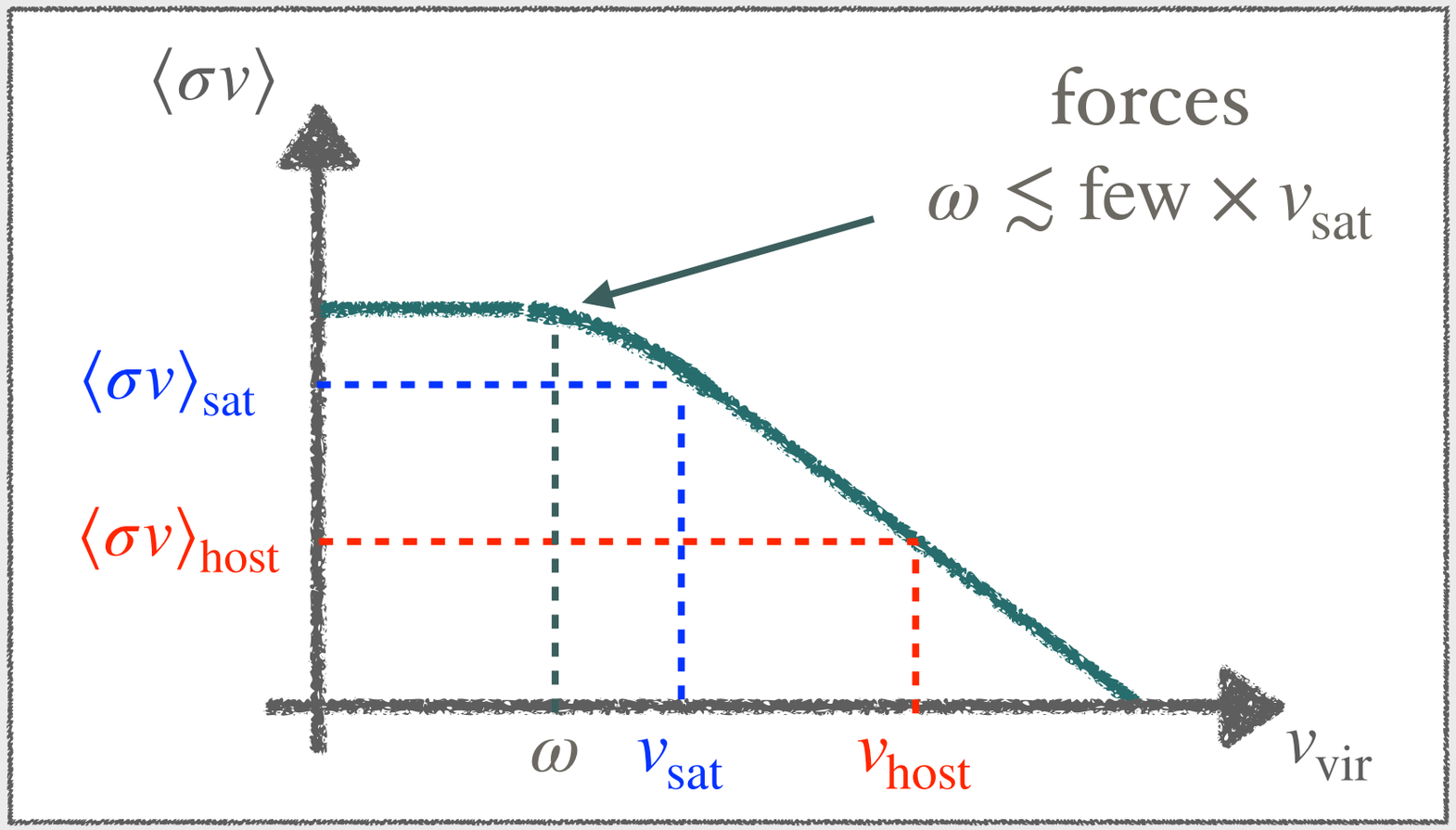
OS, F. Jiang & F. van den Bosch, PRELIMINARY

Observational Signal



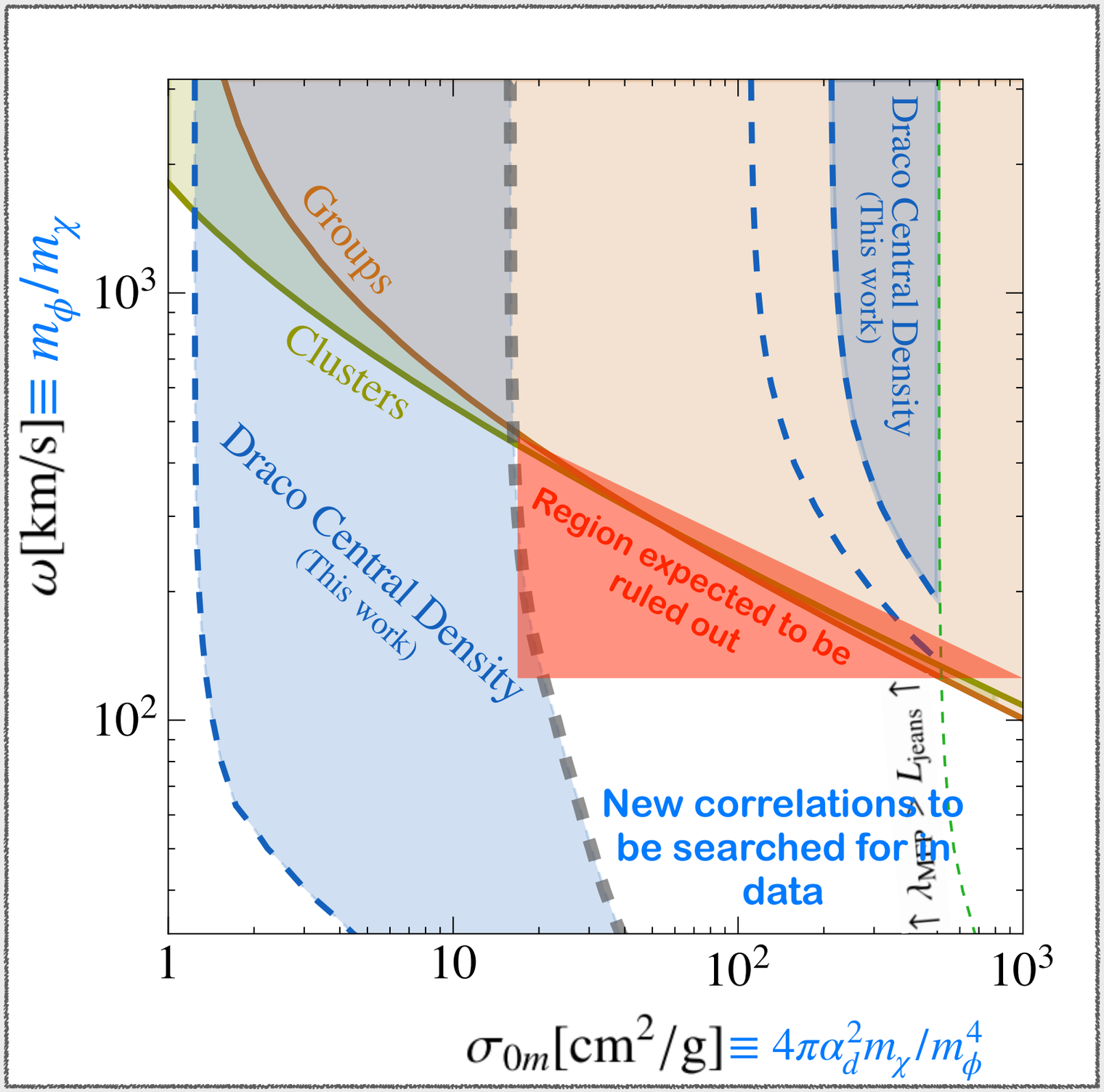
Use this to constrain SIDM

e.g. Draco must have collapsed, so: $\tilde{\Gamma}_{\rm ev,Draco} \lesssim 10^{-2}$



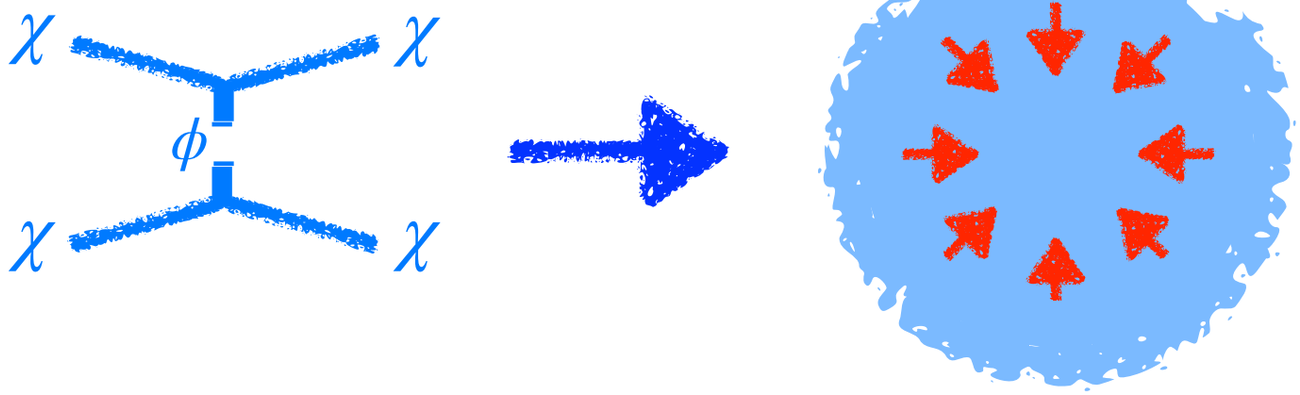
$$\frac{\rho_{\rm host}}{\rho_{\rm sat}}\frac{\langle\sigma v\rangle_{\rm host}}{\langle\sigma v\rangle_{\rm sat}} \lesssim 10^{-2} \Rightarrow \omega \equiv \frac{m_\phi}{m_\chi} \lesssim 10^2 \frac{\rm km}{\rm s}$$

Constraint on parameters

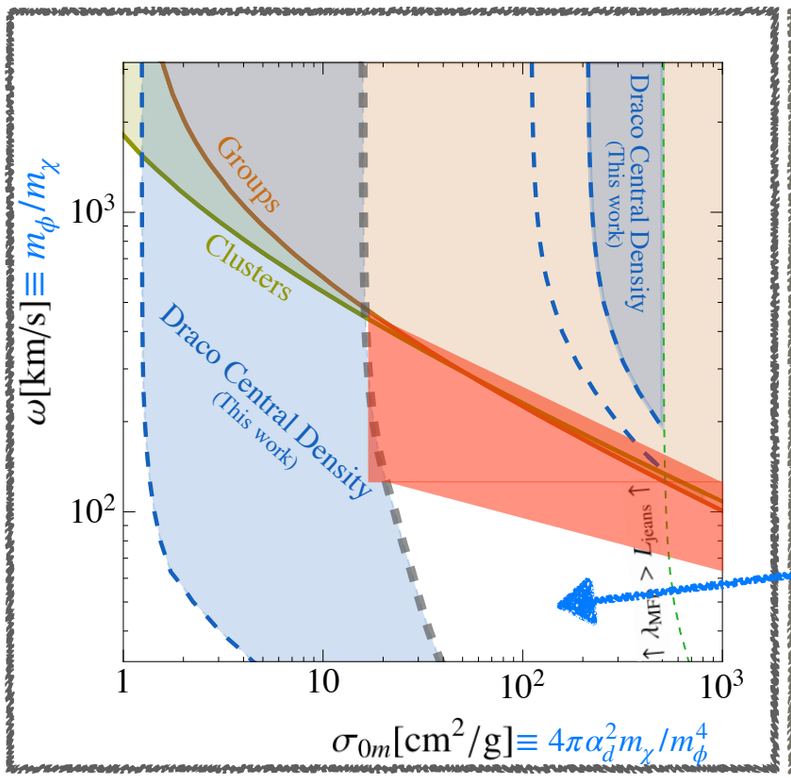


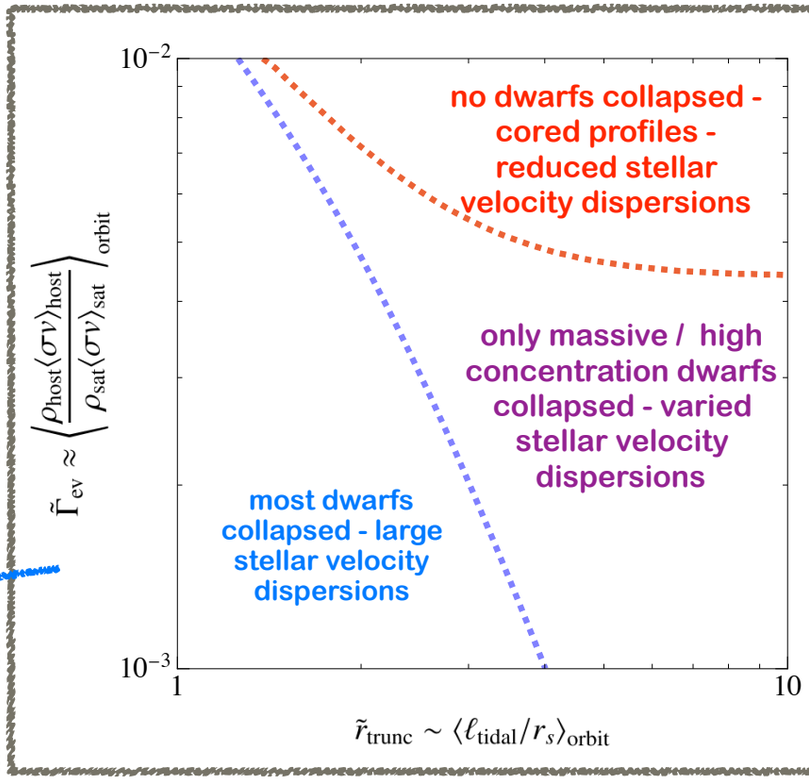
Summary and Outlook

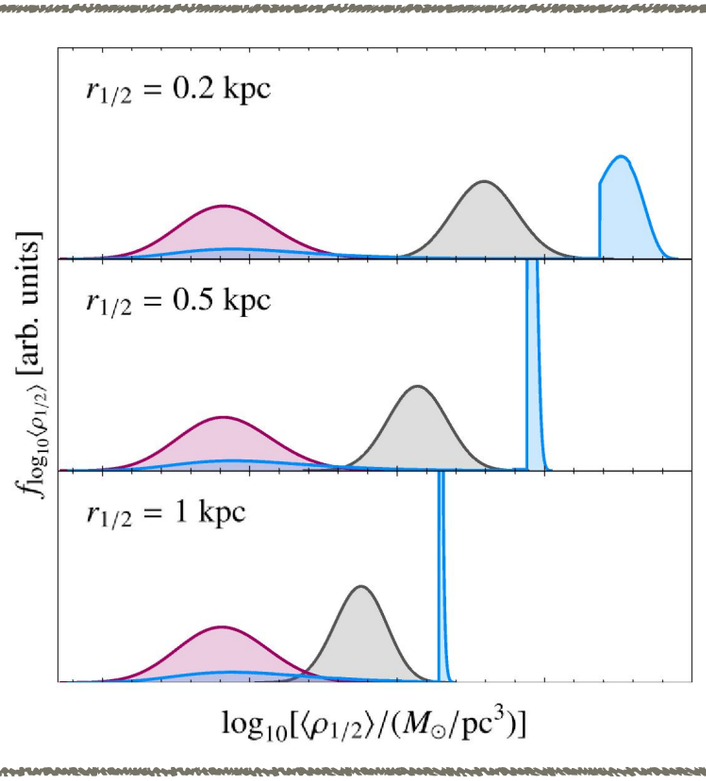
SIDM mapping:



Kinetic Theory = Powerful tool to search for dark sector signals







Thank you!