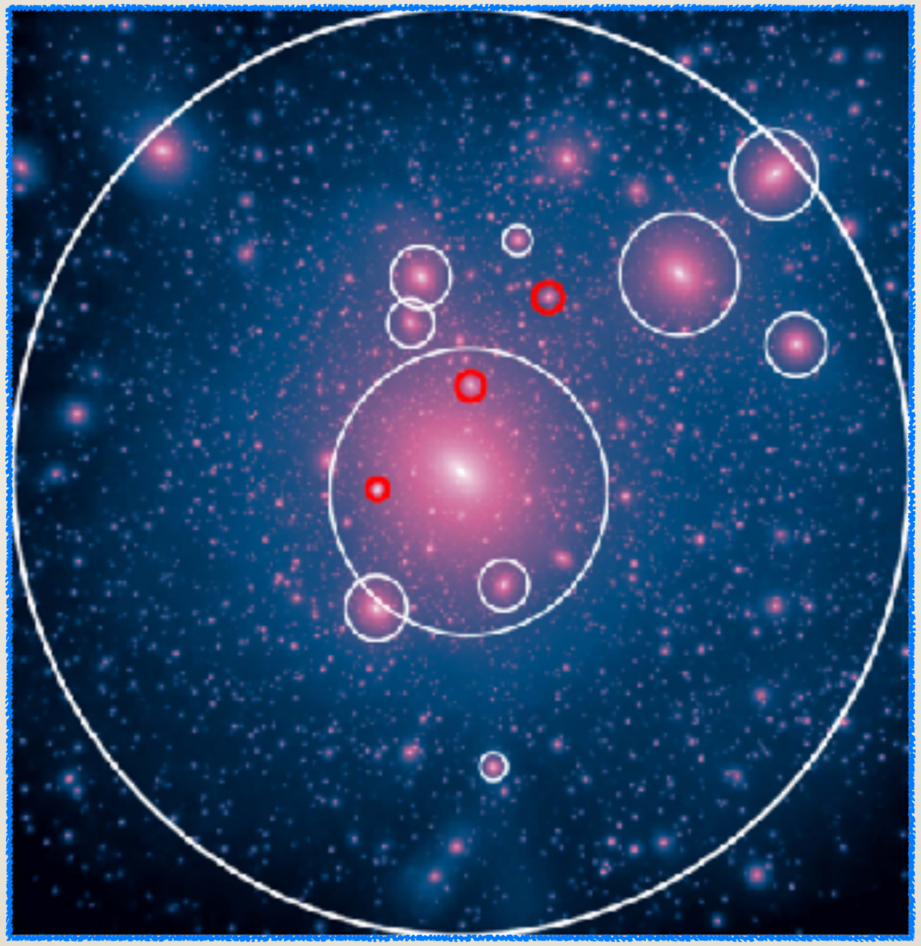
Probes of Dark Sector Physics with Galactic Substructure



Oren Slone (New York University / Princeton University)

arXiv: 2108.03243

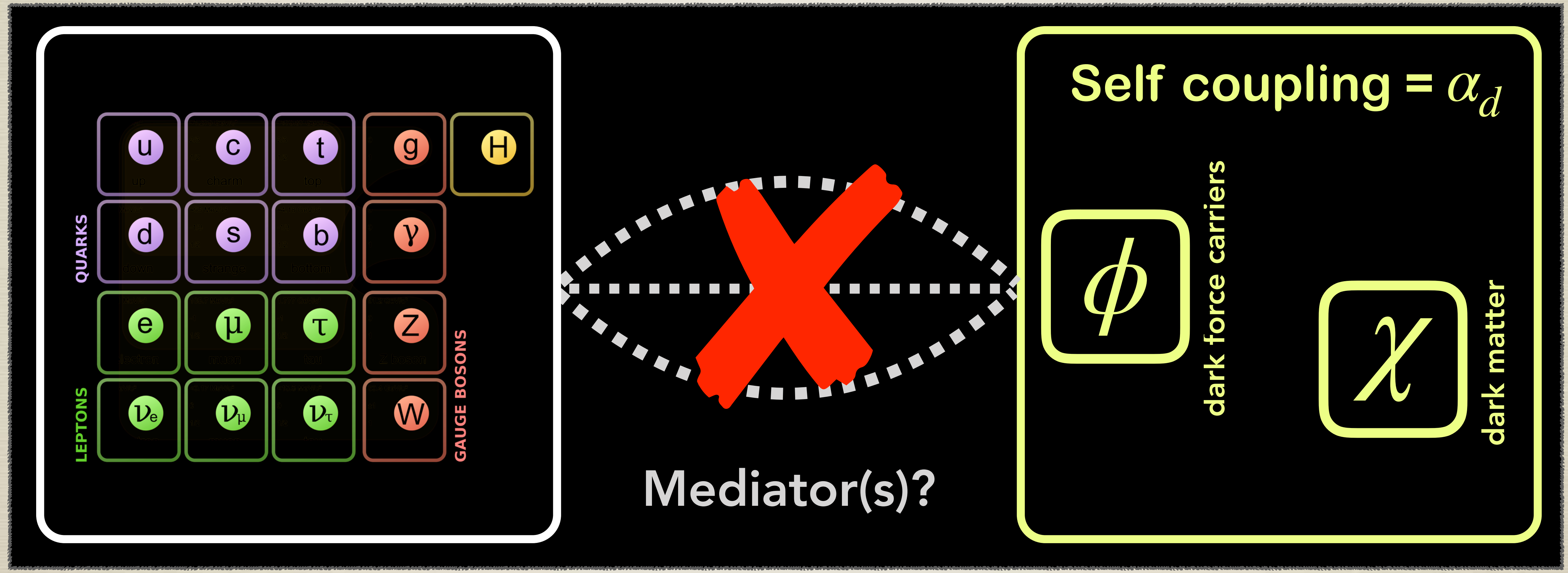
In collaboration with: F. Jiang, M. Kaplinghat, M. Lisanti

This Talk

A minimal and secluded dark sector

The Standard Model

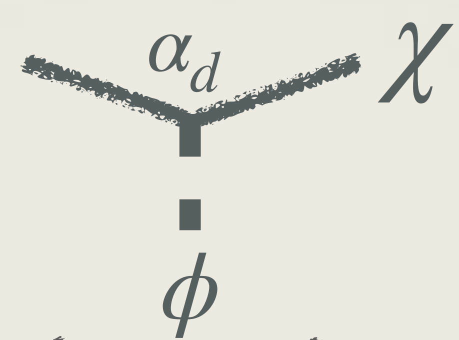
The Dark Sector



Any tiny
coupling to SM

Classes of Theories

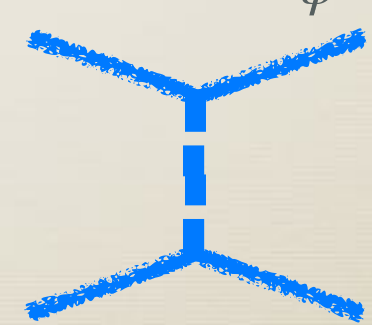
Different classes arise from different combinations of the parameters



small α_d
or
large m_ϕ

A Cold Collisionless
Dark Matter Theory

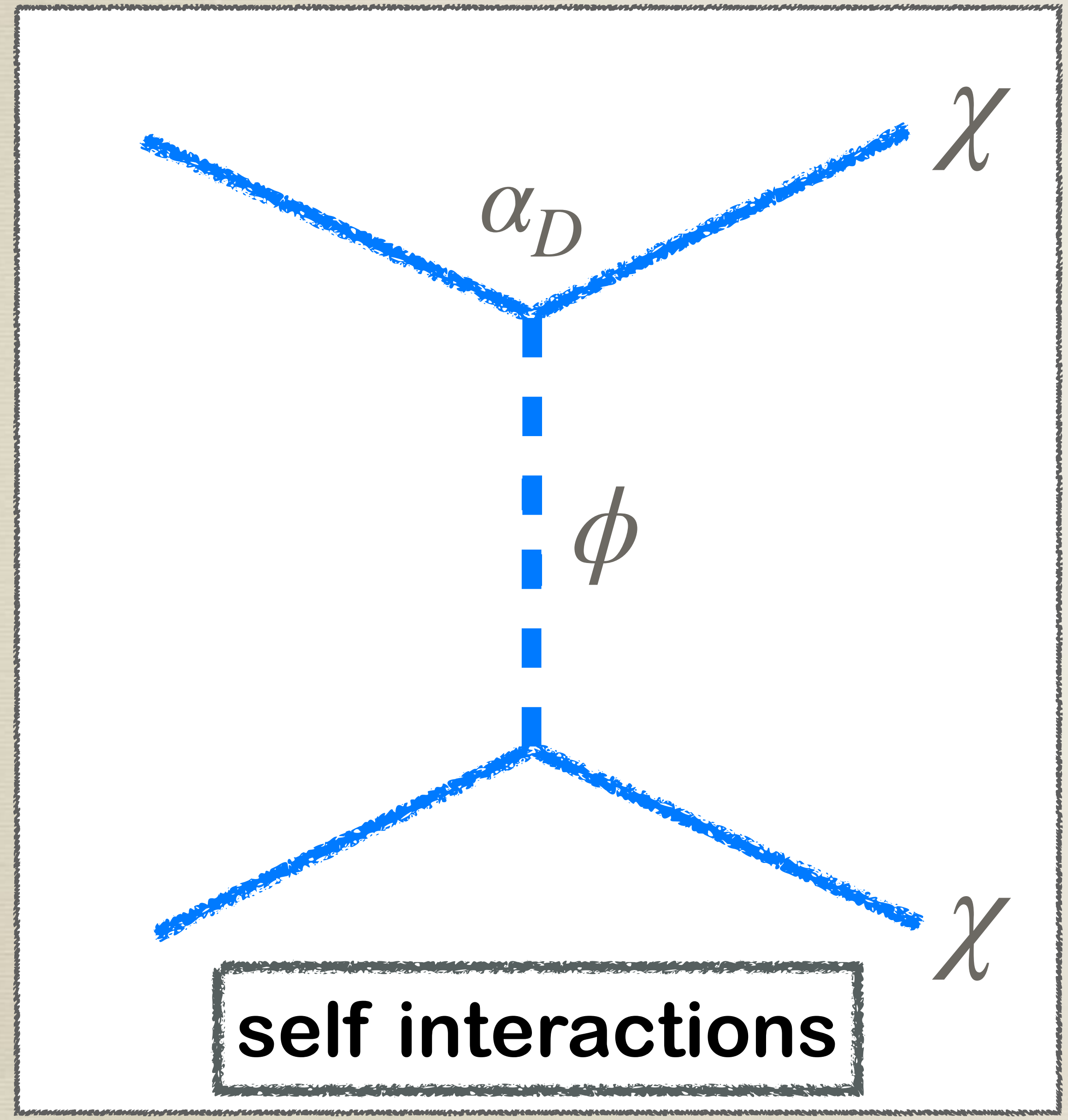
large α_d
or
small m_ϕ



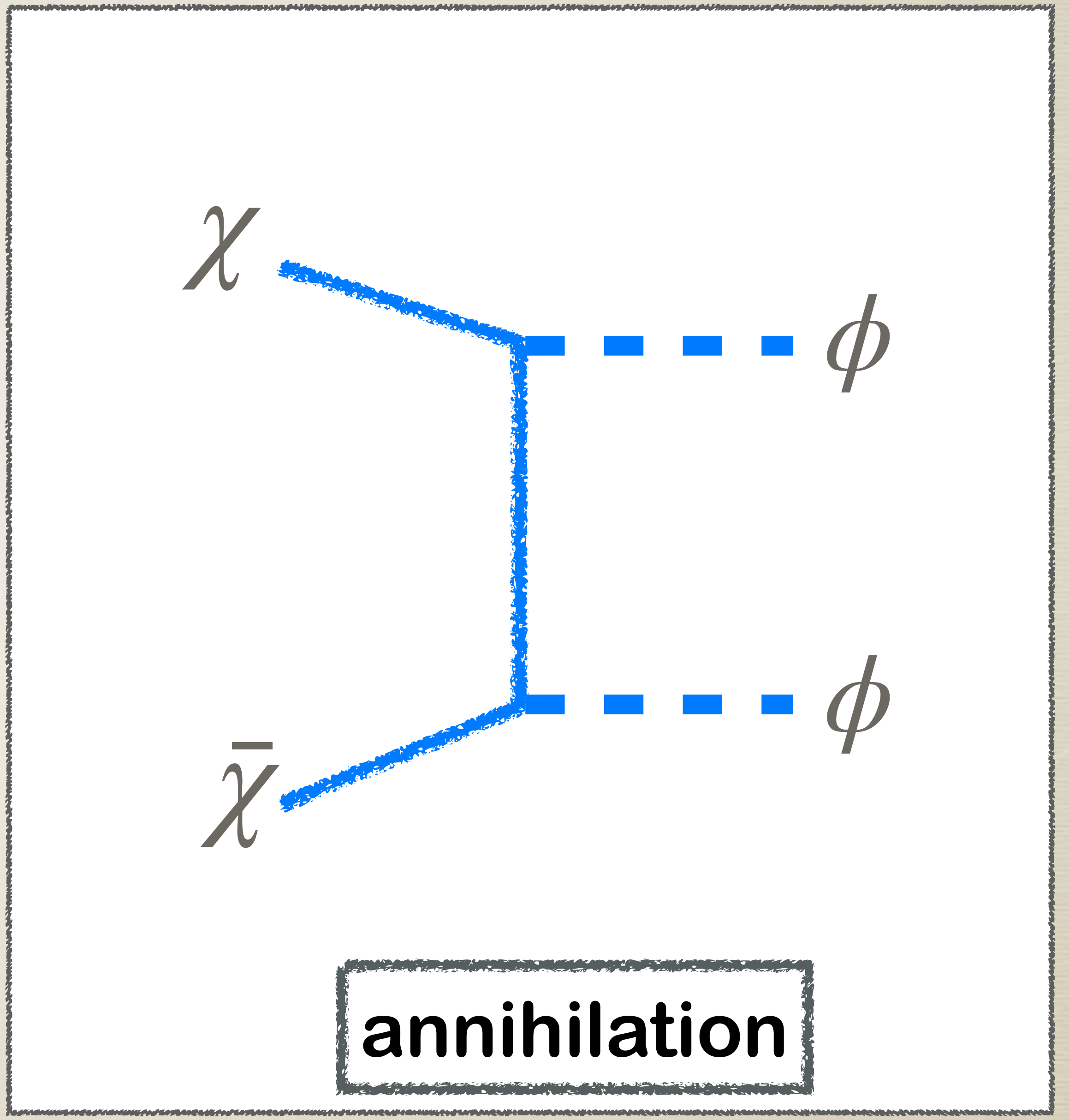
A Self-Interacting
Dark Matter Theory

Self Interacting Dark Matter Models

Detectable signatures

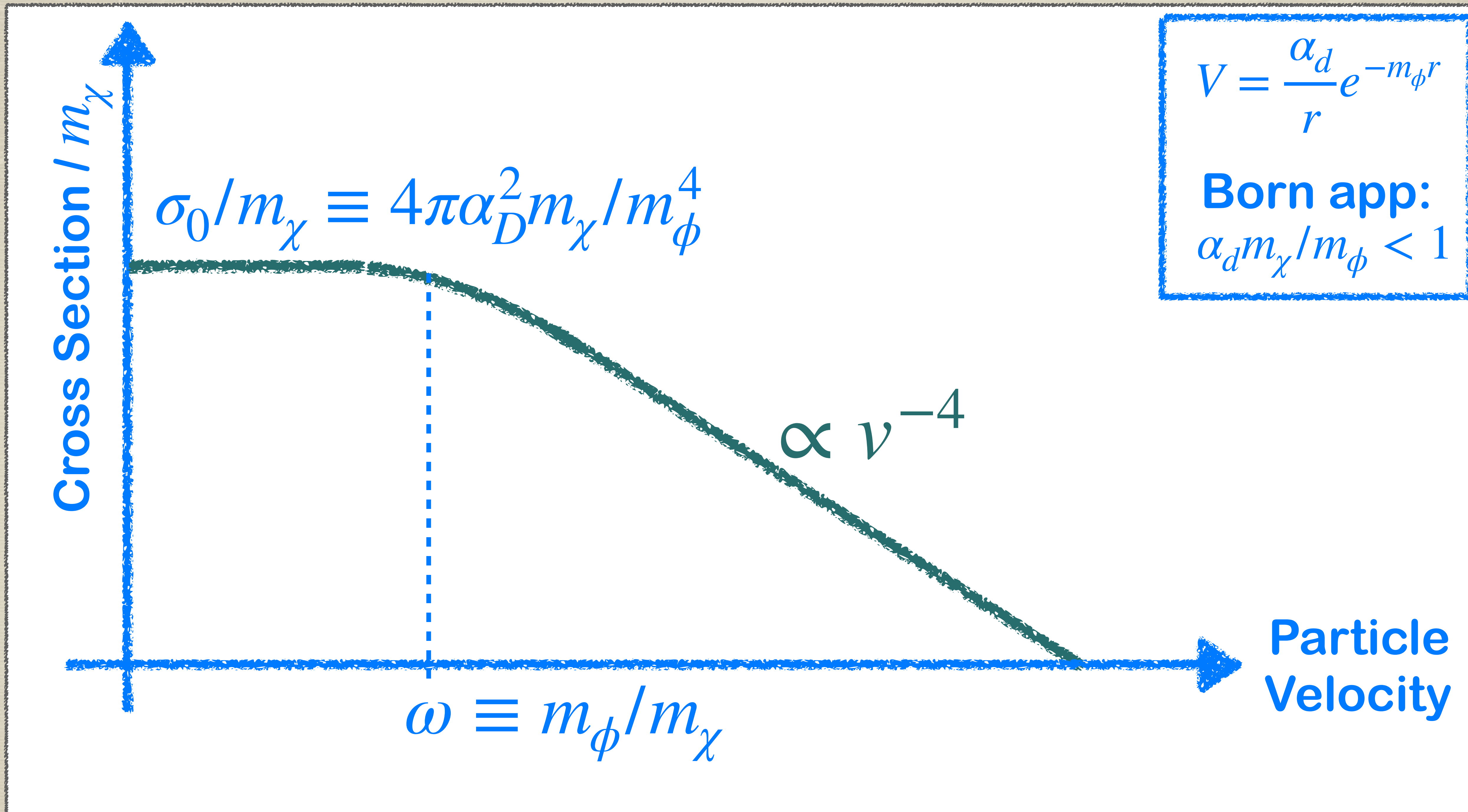


Thermal production

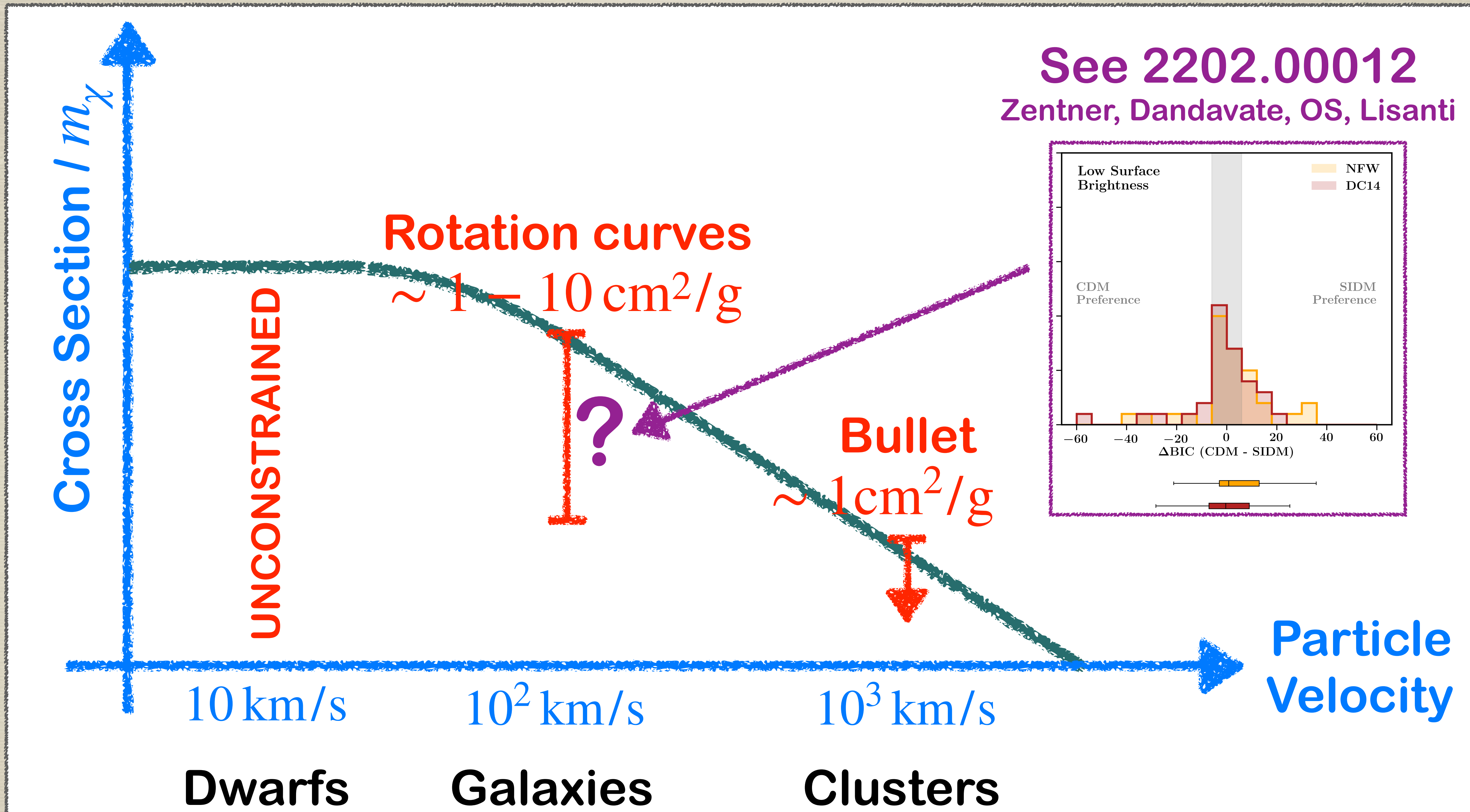


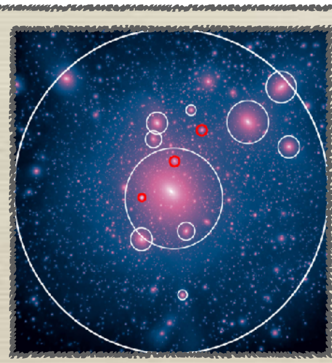
<u>**A completely secluded sector has viable production, and detectable signatures**</u>

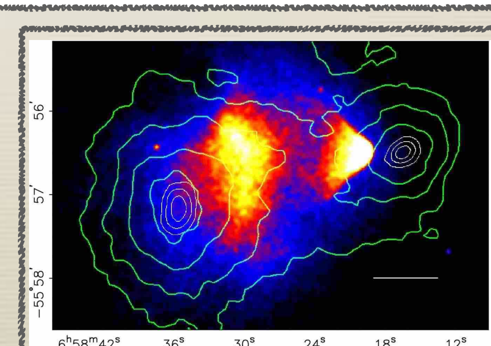
SIDM Cross Section



SIDM Cross Section







Clowe et al., 2006

Observational Consequences

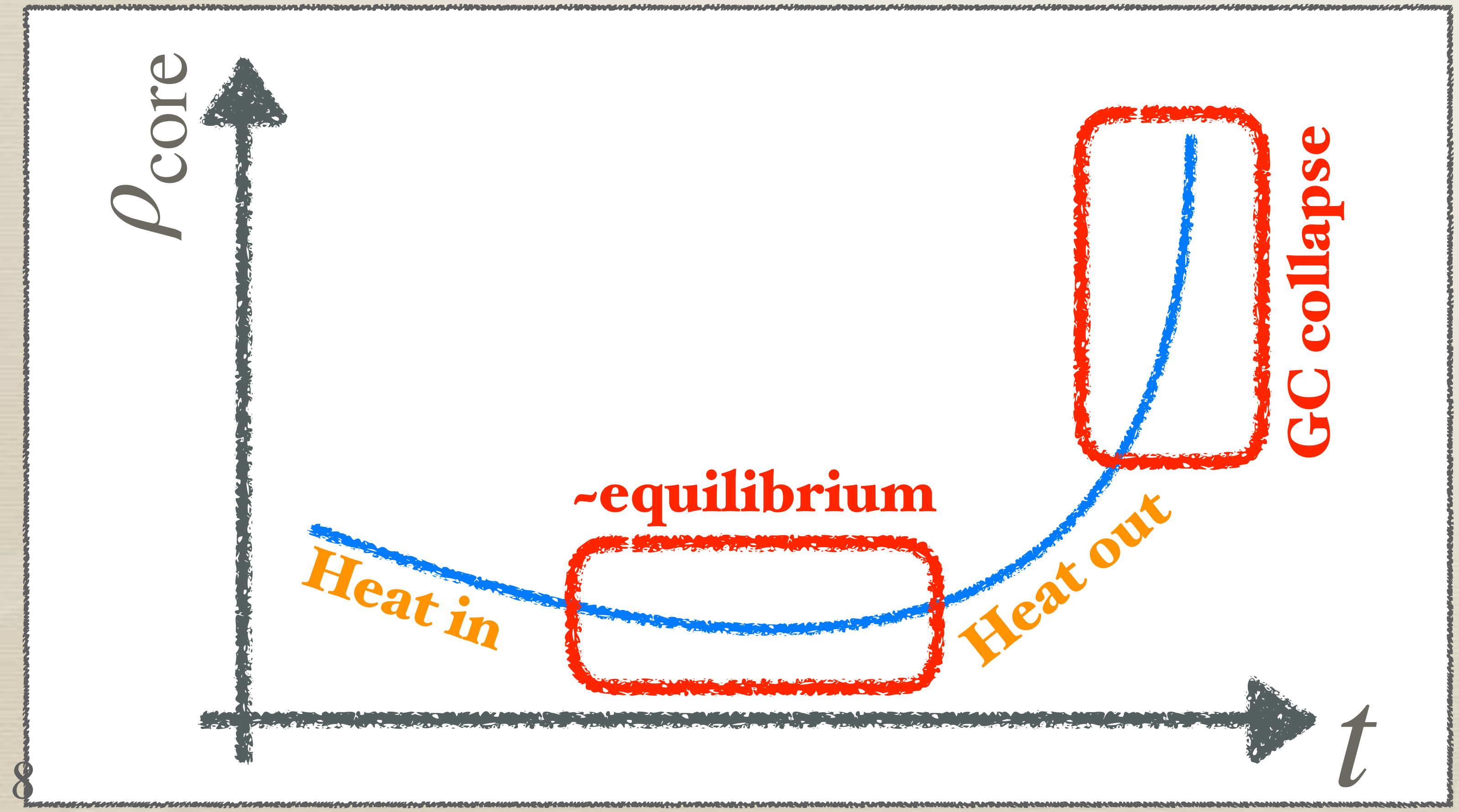
A self gravitating sphere of SIDM

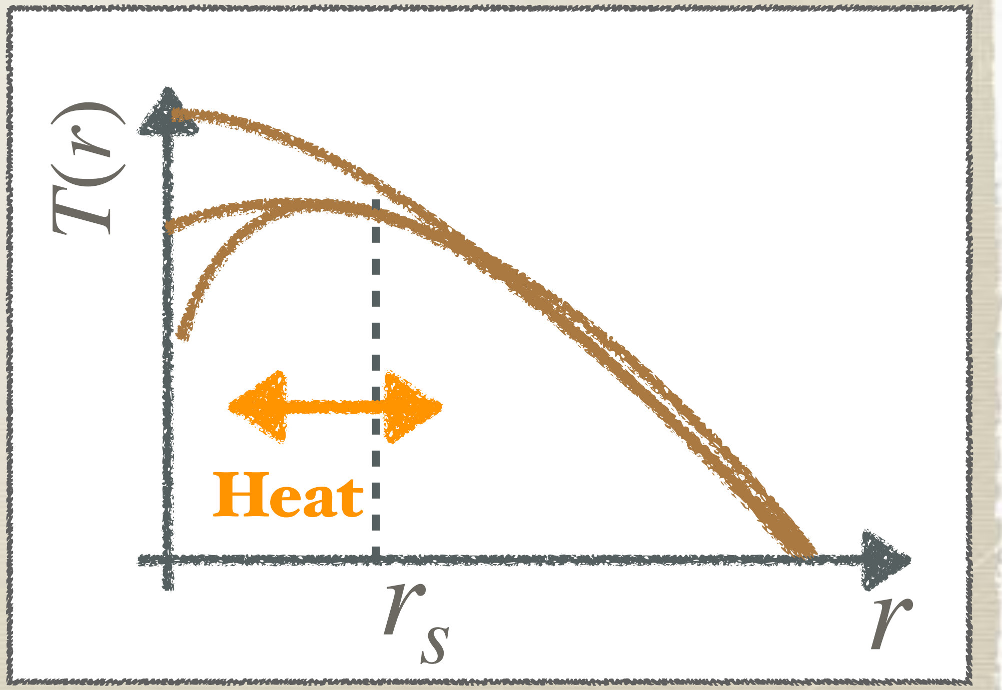
SIDM Basics

<u>**Consider a hydrodynamic description**</u>

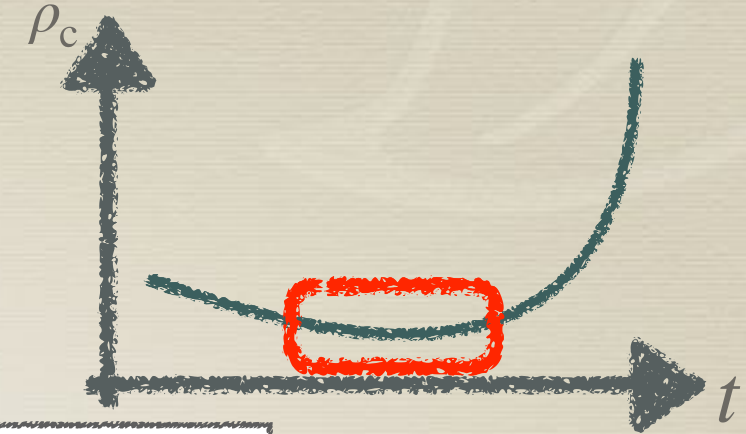
4 equations govern the dynamics:

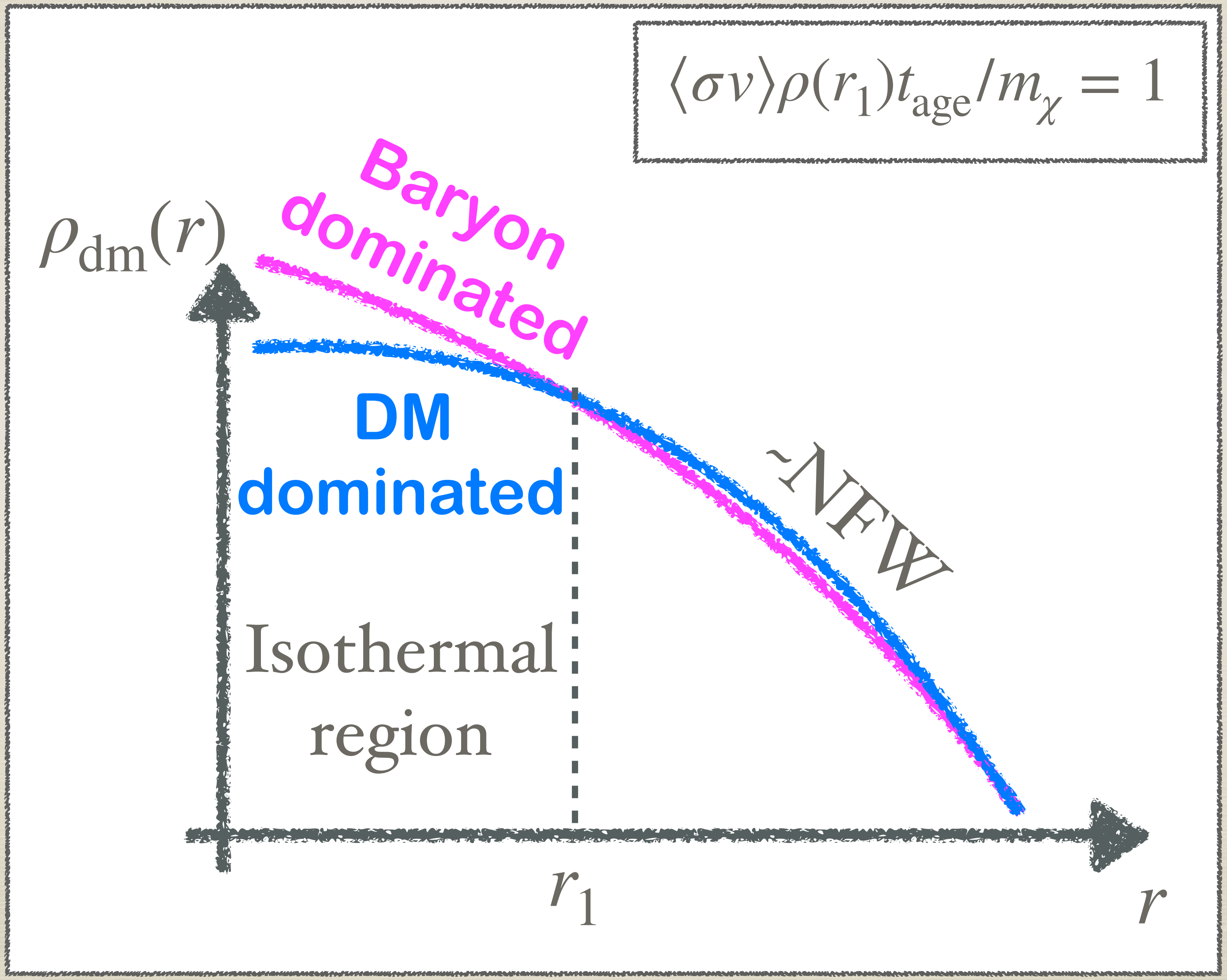
1. Mass Conservation
2. Hydrostatic Equation
3. Heat Flux
4. First Law of Thermodynamics





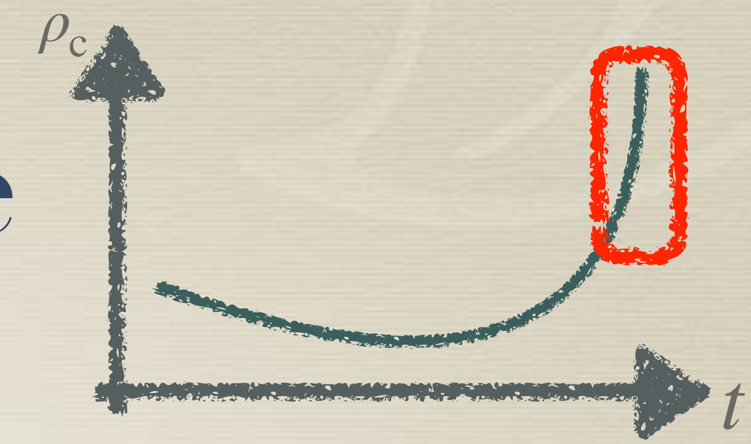
~Equilibrium Solution





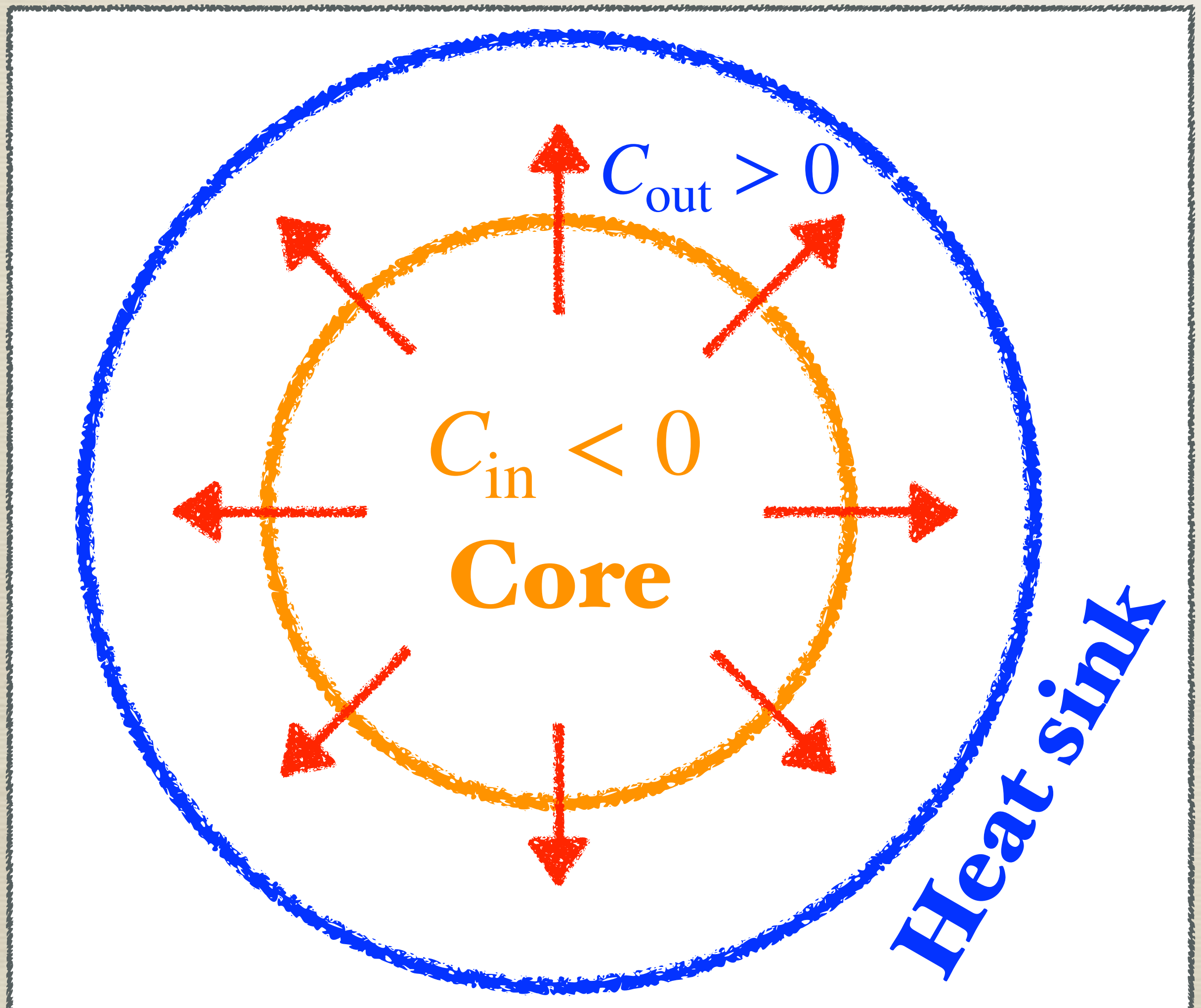
$$\rho_{iso} \propto e^{(\Phi_{bar}+\Phi_{dm})/\sigma_v^2}$$

Gravothermal Collapse Phase



Gravitationally bound and virialized systems have negative specific heat

$$0 = 2T + V = T + E \implies \boxed{E = -T}$$



As heat flows out from the hot core

↓

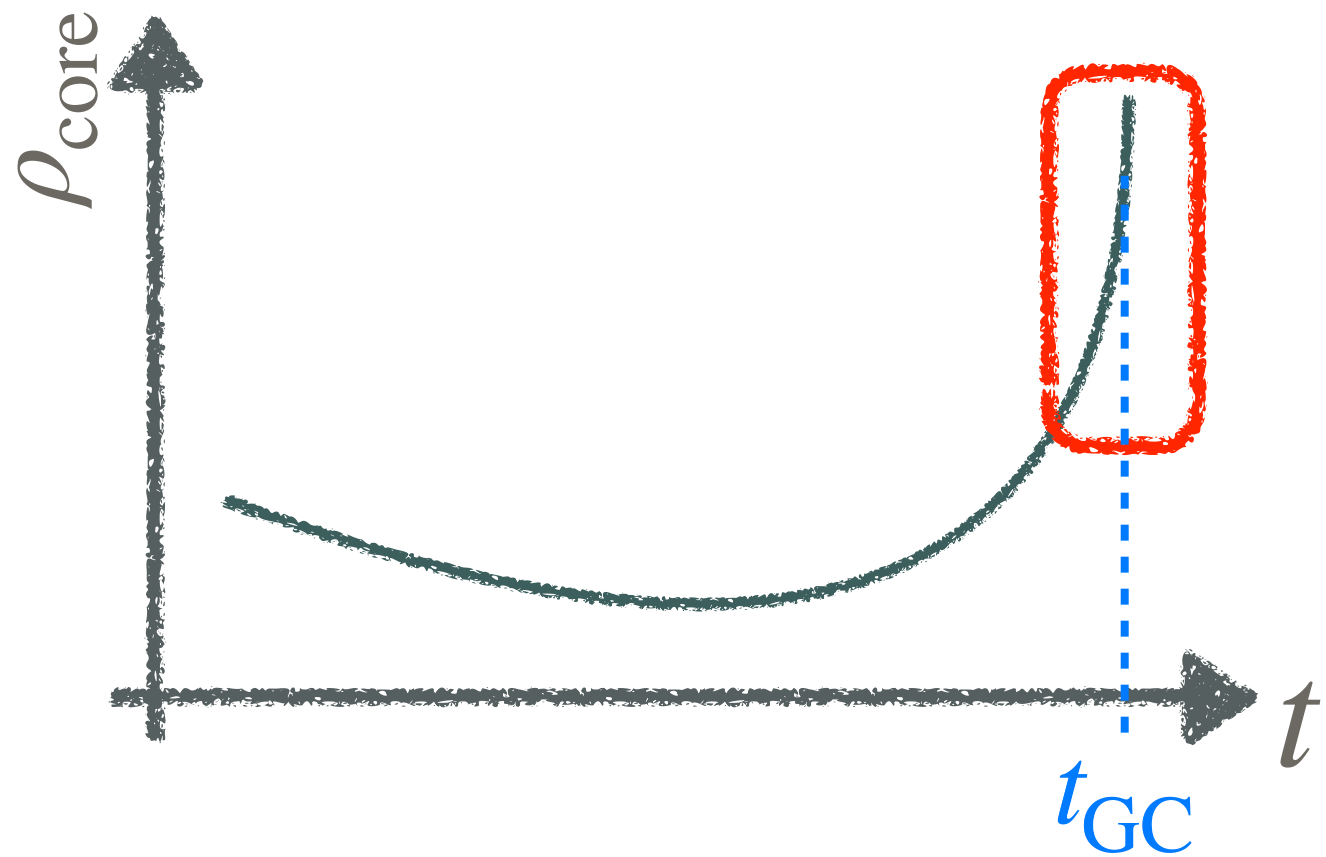
The core shrinks while T grows

Gravothermal Collapse

Timescale

When the Mean Free Path $\gg$ Core Size:

there exists an analytical solution to the equations.

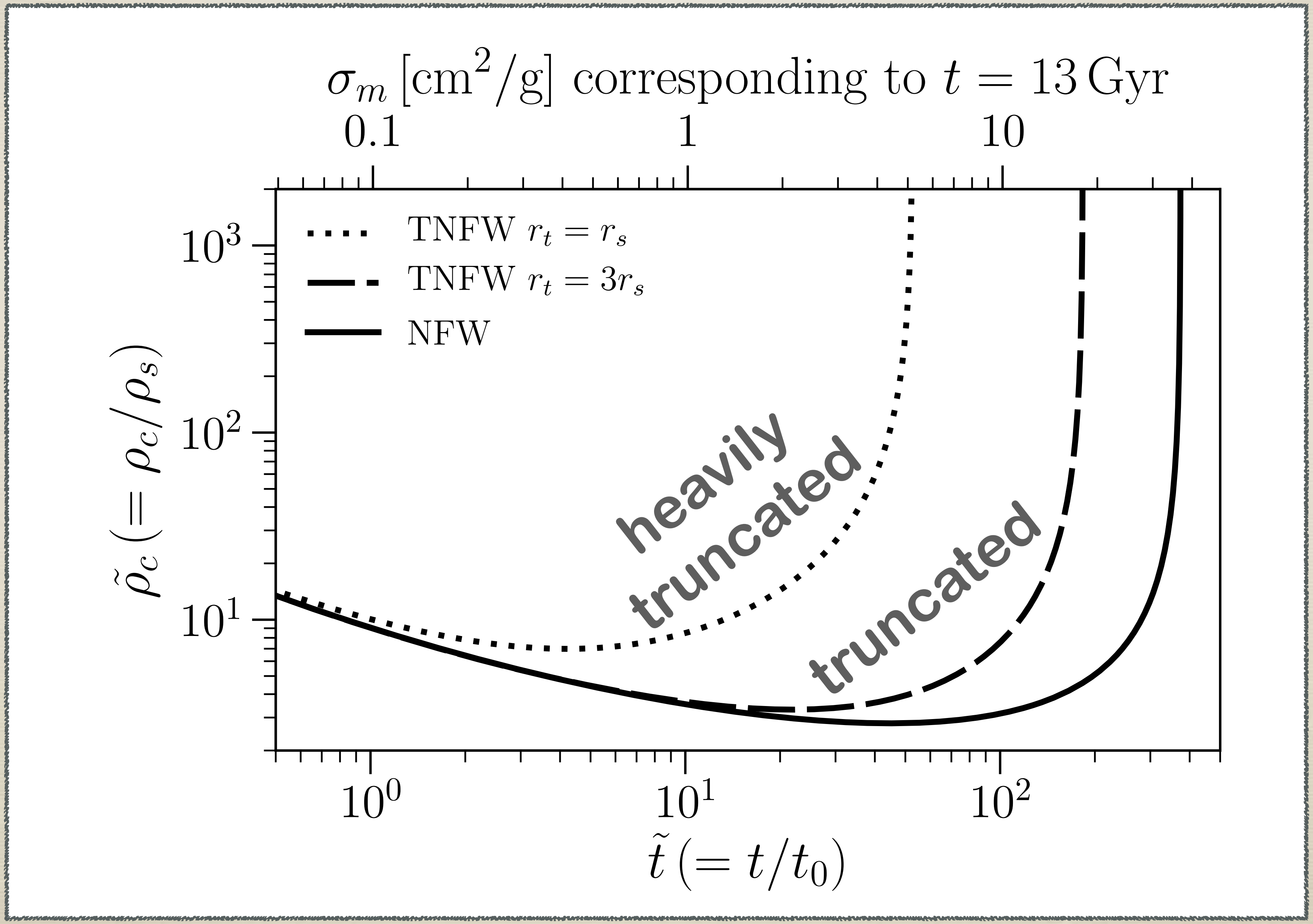


$$t_{GC} \approx 290 \left(\sigma/m_\chi v \rho\right)^{-1} \approx 700\, Gyr$$

(for $\sigma/m_\chi = 1$ cm^2/g for Draco)

Gravothermal Collapse

Accelerated by Stripping



Nishikawa et. al., 2020

Intermediate Summary

Particle physics / Astrophysics	CDM satellites	SIDM satellites
Cores	NO	YES, below $\sim r_1$
Gravothermal Collapse	NO	YES, at large σ/m_χ or when stripped

Comparing Theory to Data

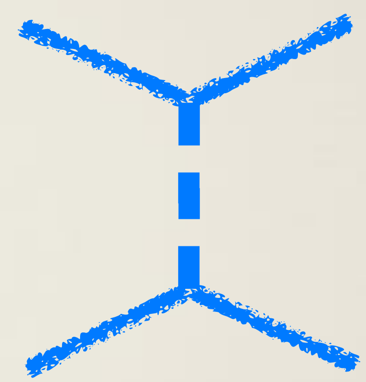
<u>Given a DM theory</u>

e.g.

CDM

**Your favorite
Cold Collisionless
DM theory**

SIDM



<u>Predict statistical properties such as:</u>

- **# satellites as function of** $r\,/\,r_{\mathrm{peri}}$
- **Satellite mass distribution**
- **Central densities of satellites**

Comparing Theory to Data

Simulations → Yes, but some challenges.

An alternative approach

- Understand what effects SIDM has on satellites
- Model those effects semi-analytically
- Scan over parameters and predict trends and signals
- Verify results with dedicated simulations

Satellite Orbital Evolution

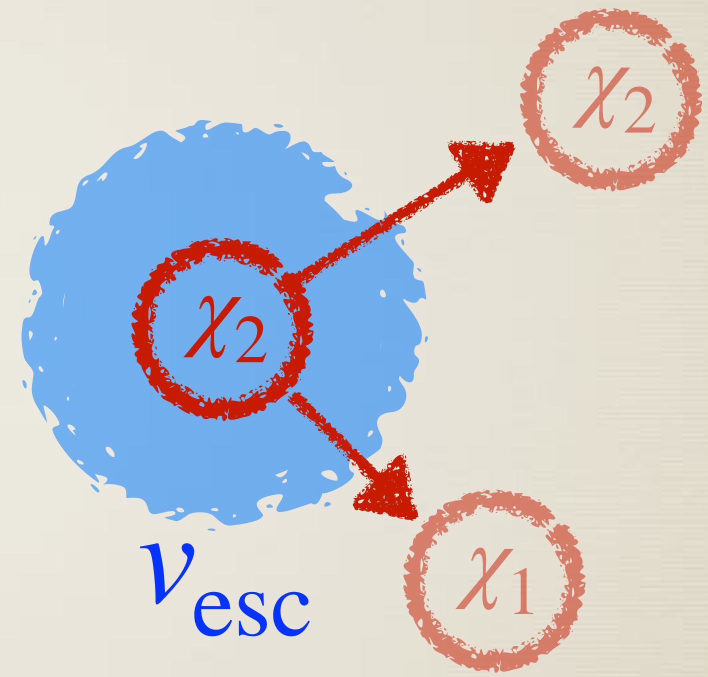
Additional Observational Consequences

Ram Pressure

Evaporation / Deceleration from SIDM Interactions

Host particle

Satellite particle



Since $v_{sat} \gg v_{esc} \implies$ **Most scatterings result in:**

1. **Escape of both particles**
2. **Little momentum transfer**

Intermediate Summary

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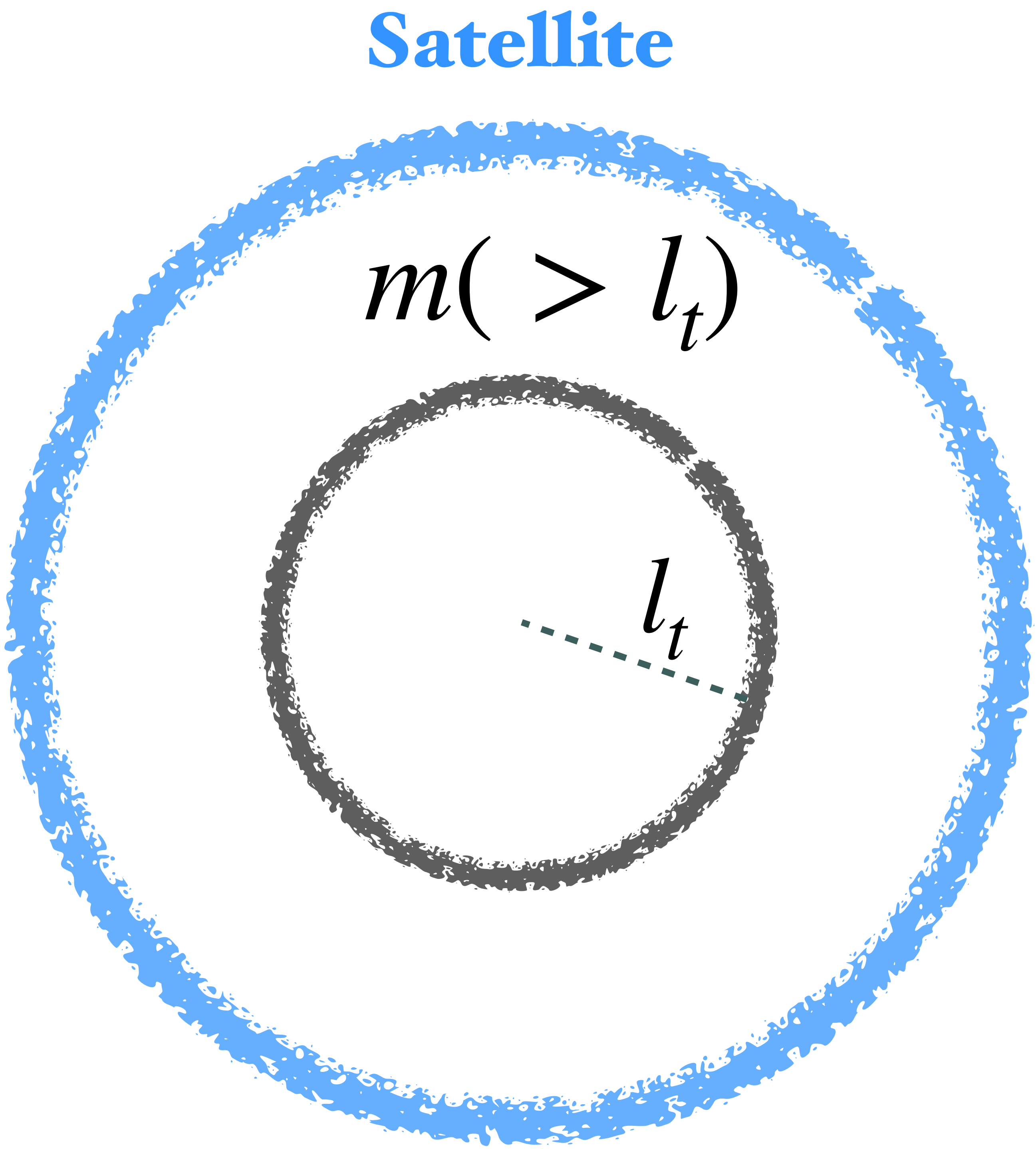
Gravothermal Collapse	NO	YES, at large σ/m_χ or when stripped
Ram Pressure Evaporation	NO	YES, after most scatters
Ram Pressure Deceleration	NO	YES, at large σ/m_χ

Satellite Evolution

Tidal Stripping



Cored profile→Small l_t
$\Longrightarrow$ Large $m(>l_t)$

Particle physics / Astrophysics	CDM satellites	SIDM satellites
Cores	NO	YES, below $\sim r_1$
Gravothermal Collapse	NO	YES, at large σ/m_χ or when stripped
Ram Pressure Evaporation	NO	YES, after most scatters
Ram Pressure Deceleration	NO	YES, at large σ/m_χ
Tidal Stripping	YES	YES, but more

Incorporate all relevant physics into an orbit integrator.

Compare models and identify parameters of interest.

RESULTS

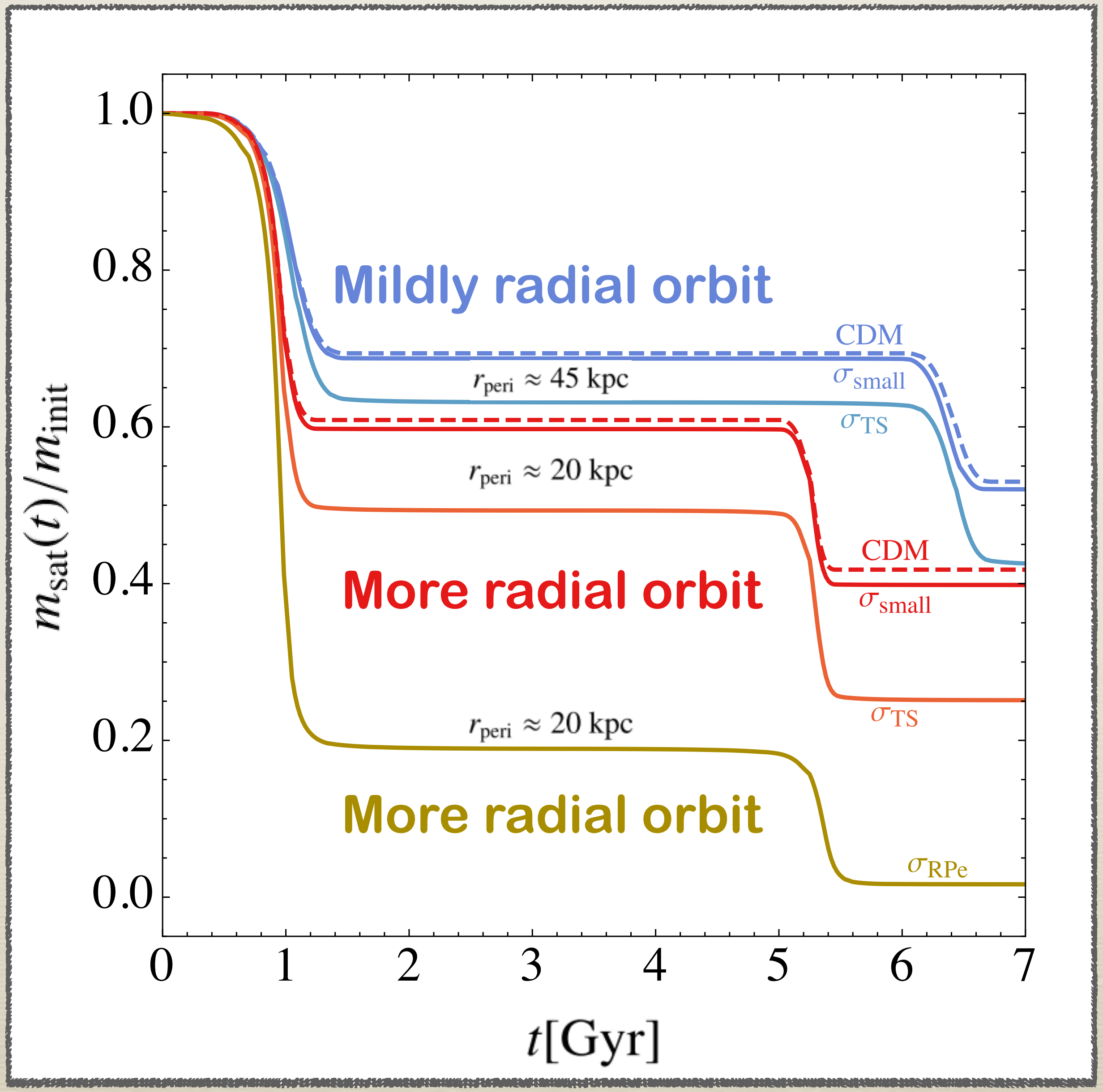
Examples of Mass Loss

Three example cross sections:

σ_{small} **Same as CDM**

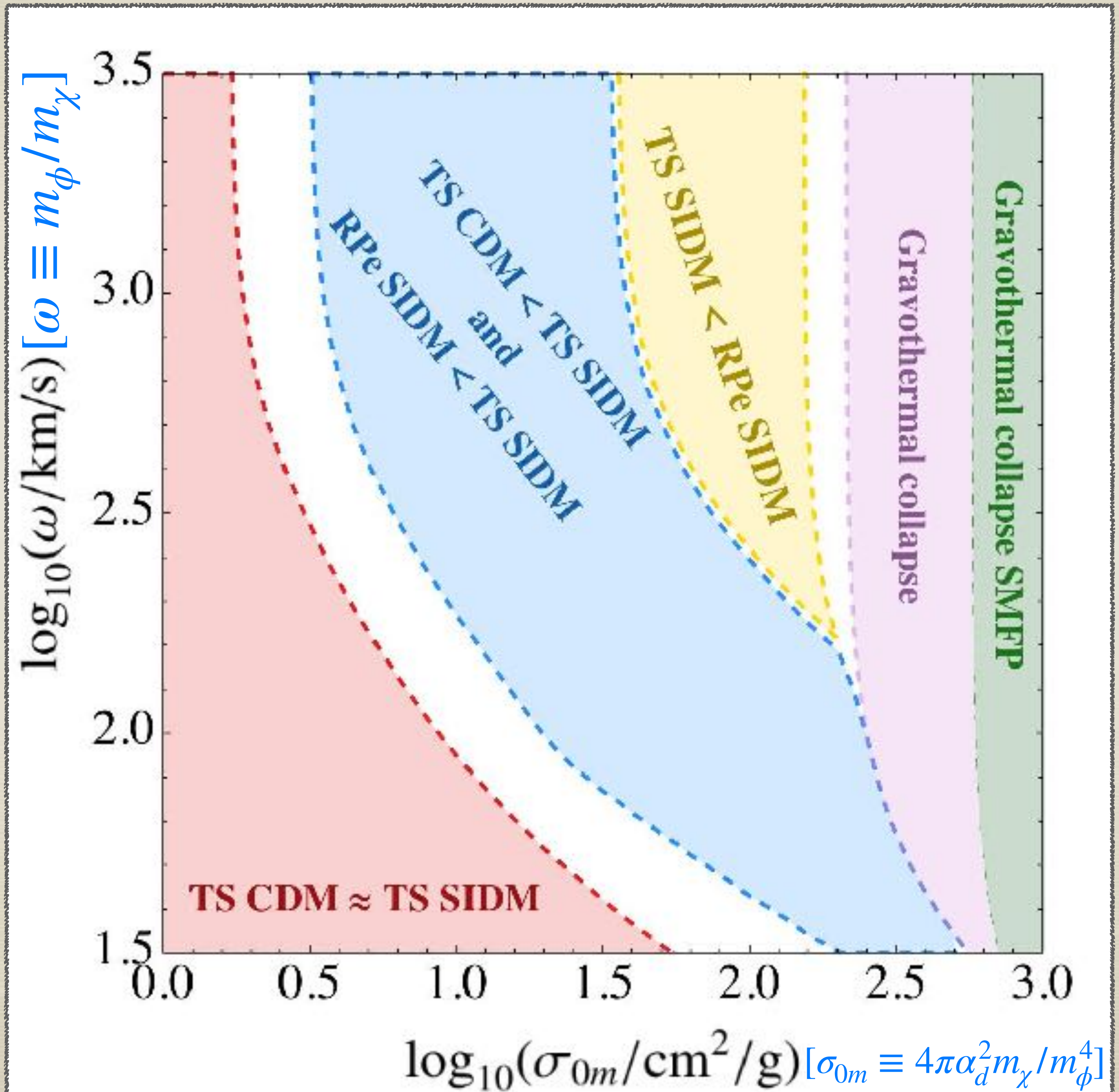
σ_{TS} **Mass loss dominated by Tidal Stripping**

σ_{RPe} **Mass loss dominated by Ram Pressure Evaporation**



OS+, 2021

SIDM Parameter Space

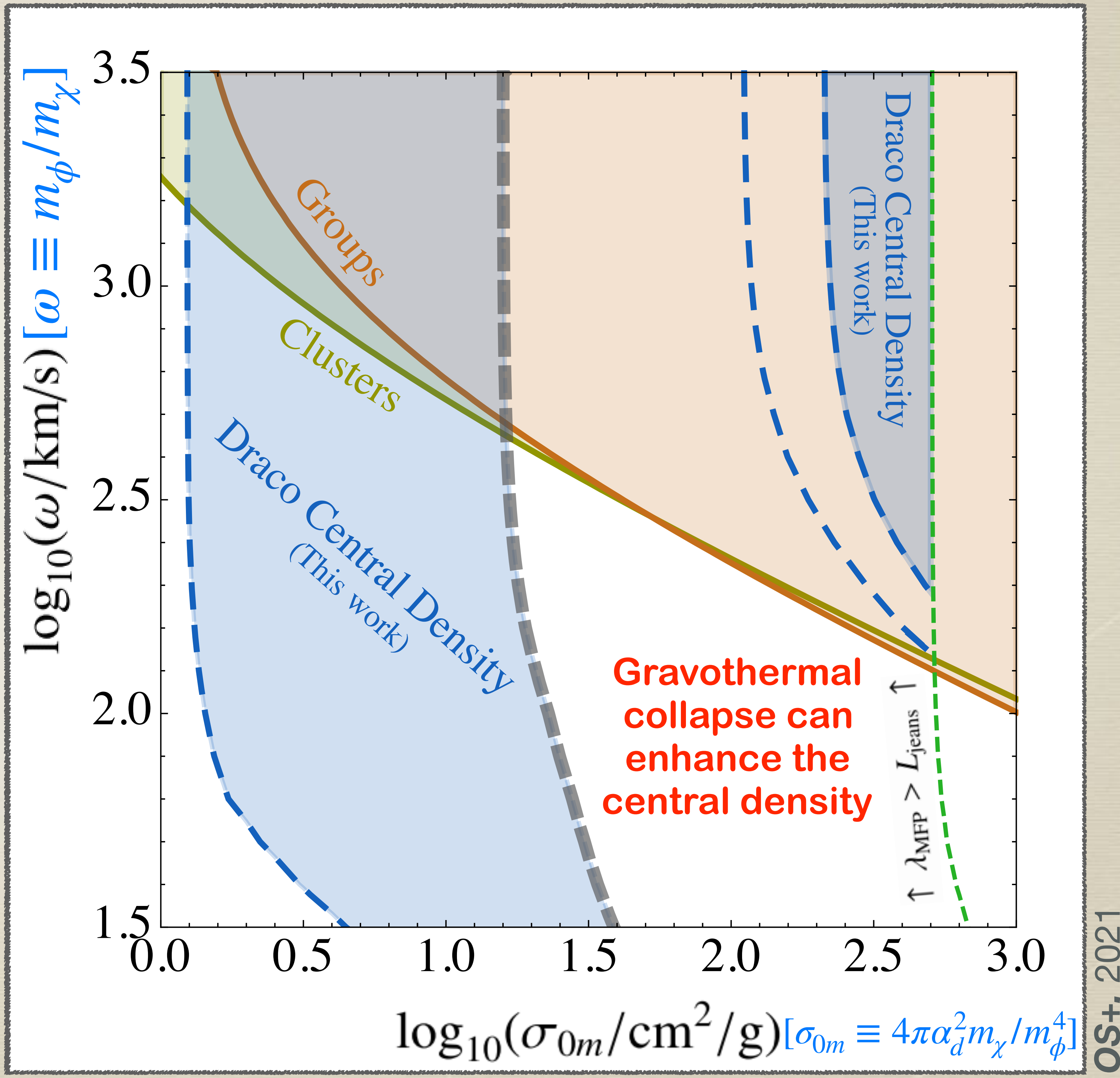


OS+, 2021

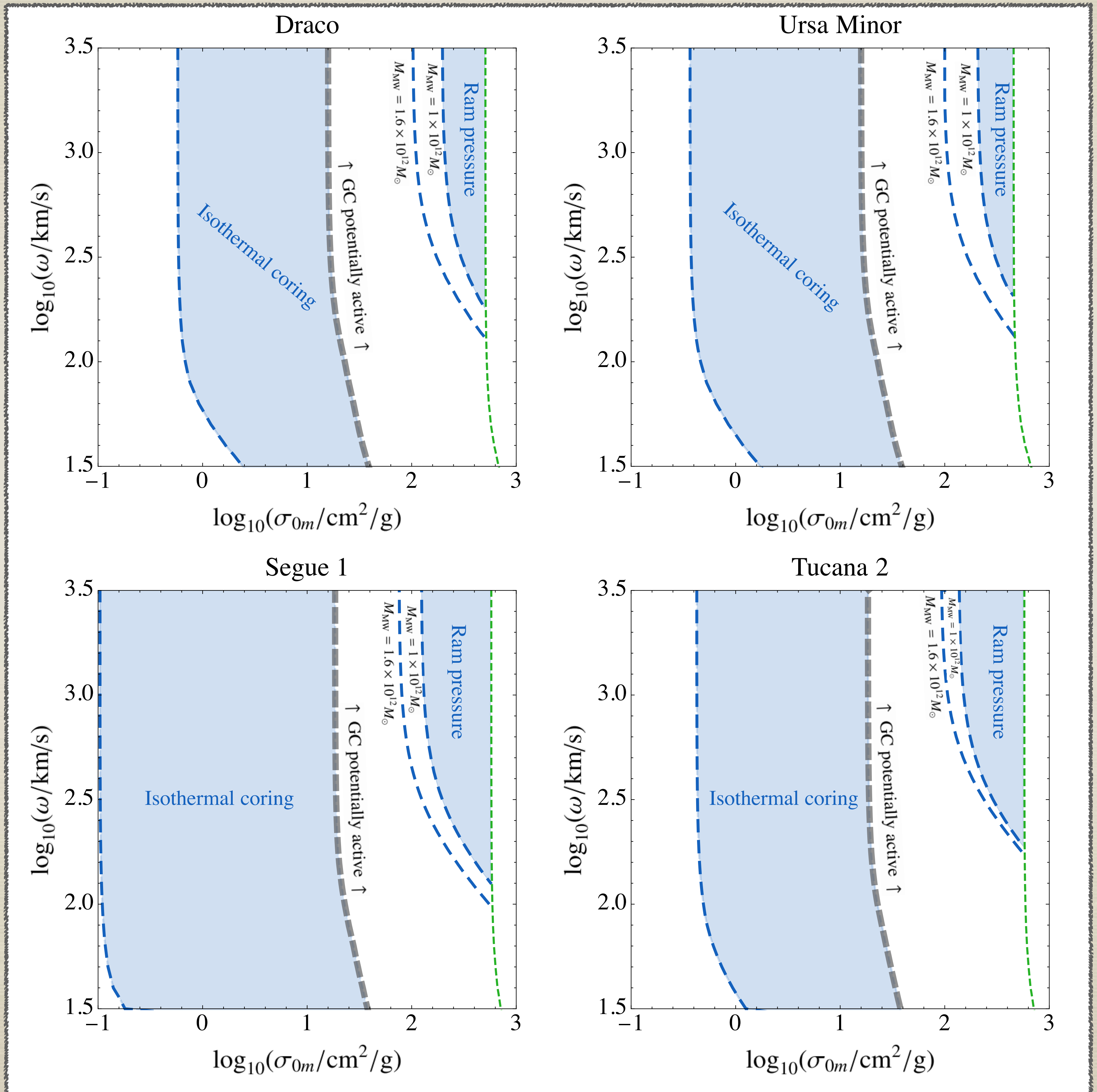
Bounds from Dwarfs

Draco's measured central density:

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



Consistent Results for other Dwarfs

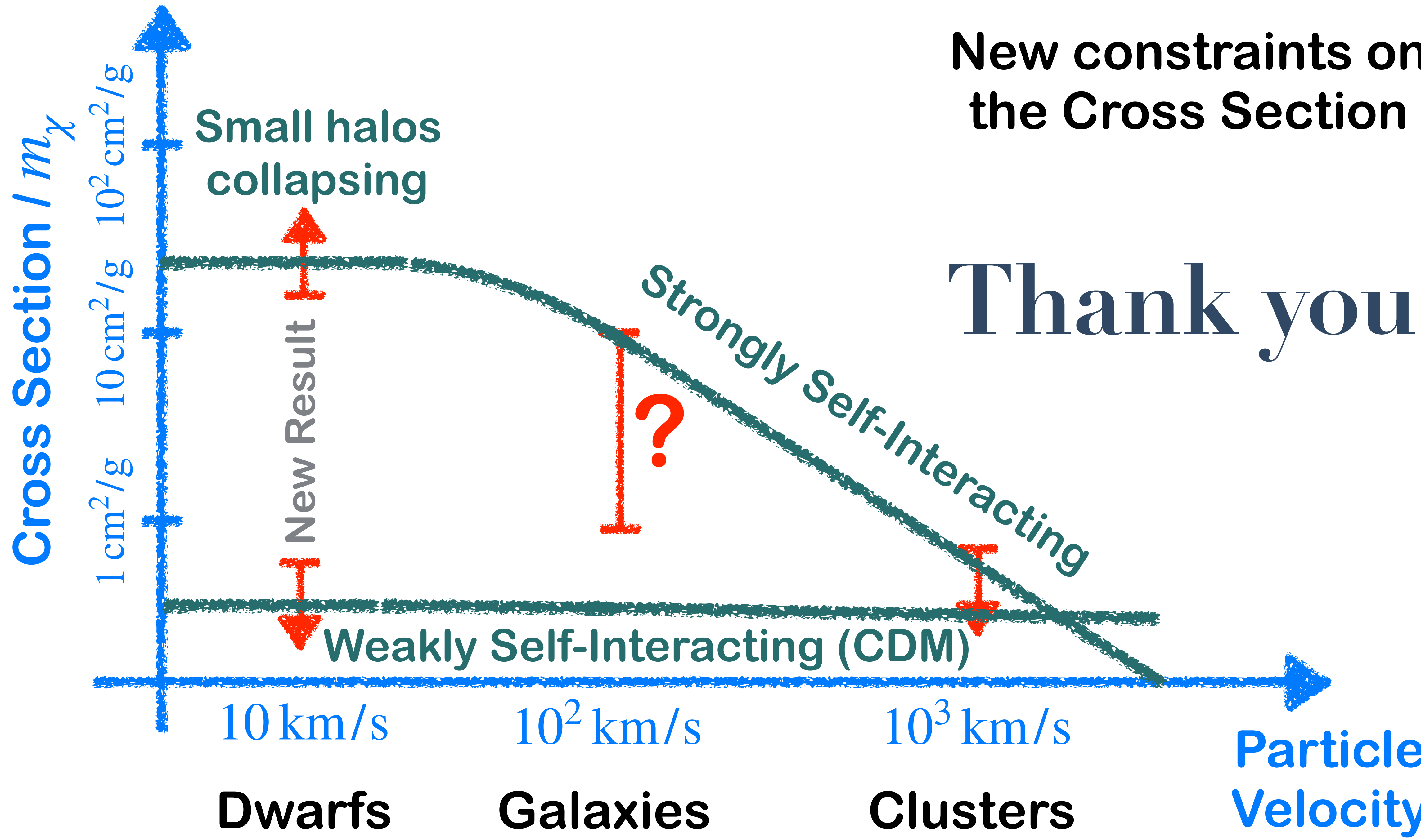


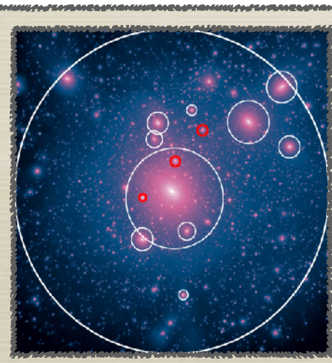
OS+, 2021

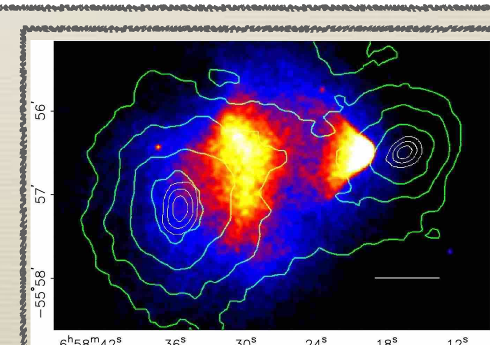
Summary

New constraints on the Cross Section

Thank you!







Clowe et al., 2006