Tidal Stripping of SIDM Halos

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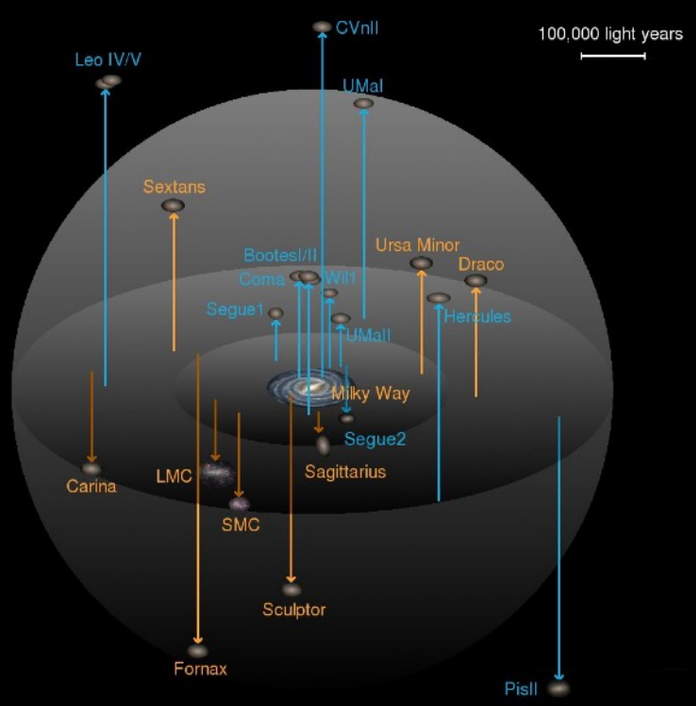
LSST Dark Matter Workshop

5-7 August 2019

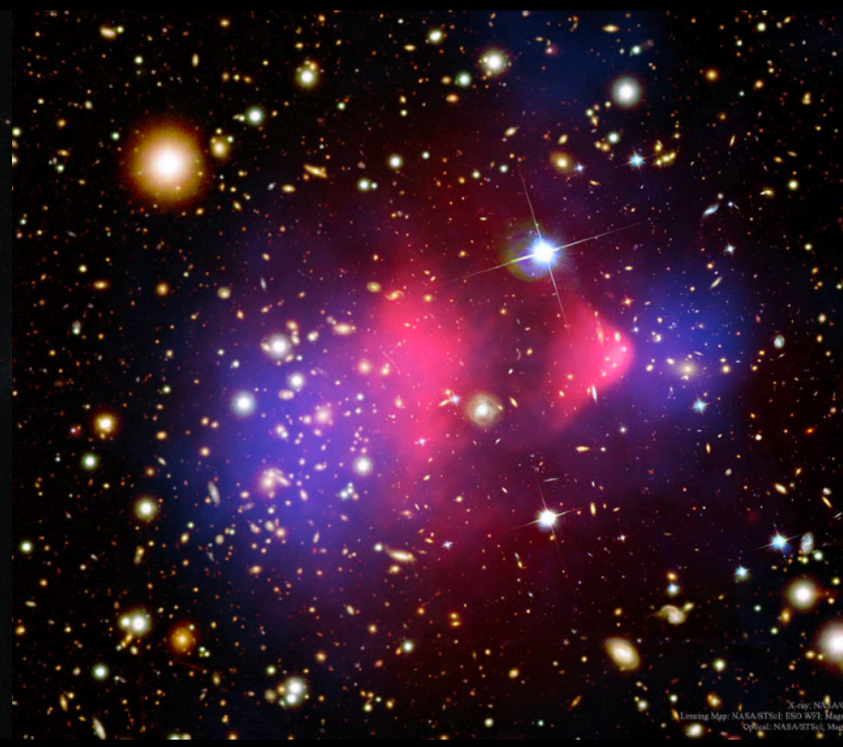
Small-Scale Structure

Dwarf spheroidals



LSBs

Galaxy Clusters



small-scale structure puzzles arise in various systems:
core-cusp, missing satellites, too-big-to-fail, diversity

SIDM Solution

Alleviate tensions?

Spergel and Steinhardt, PRL (2000)
Rocha+, MNRAS (2013)
Zavala+, MNRAS (2013)

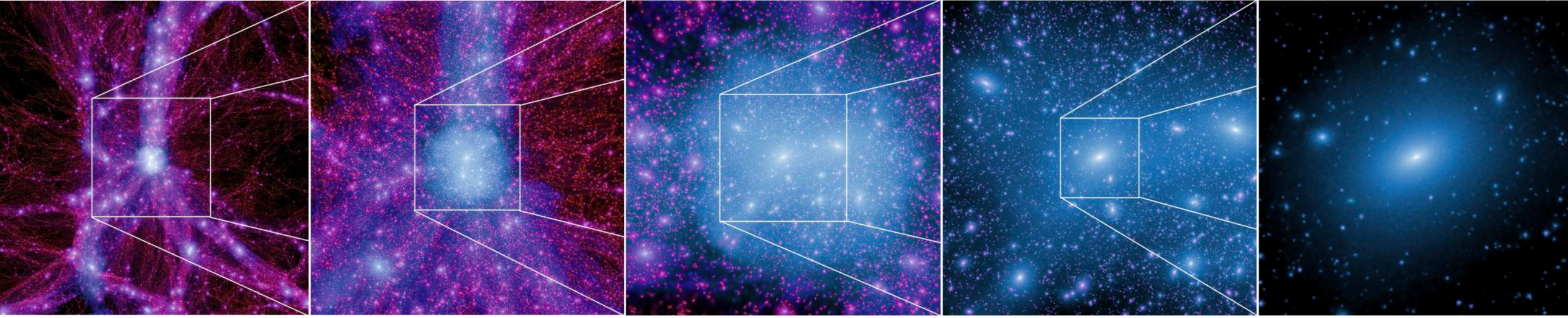
Dwarfs

LSBs

Clusters

Further investigations with SIDM+baryons are ongoing

Kaplinghat, Tulin, Yu, PRL (2016)



Millennium-II, *Boylan-Kolchin+ (2009)*

Can we understand SIDM halo evolution without needing to run N-body simulations?

Yes! Use semi-analytic methods.
Gravothermal evolution.

In globular clusters:

- *Lynden-Bell and Eggleton (1980)*

In SIDM halos:

- *Balberg, S. Shapiro, Inagaki (2002); Ahn, P. Shapiro (2004); Koda, P. Shapiro (2011)*

Gravothermal Evolution

- Mass conservation

$$\frac{\partial M}{\partial r} = 4\pi r^2 \rho$$

- Hydrostatic equilibrium

$$\frac{\partial(\rho\nu^2)}{\partial r} = -G\frac{M\rho}{r^2}$$

- Laws of thermodynamics

$$\frac{\partial L}{\partial r} = -4\pi r^2 \rho \nu^2 \left(\frac{\partial}{\partial t}\right)_M \ln\left(\frac{\nu^3}{\rho}\right)$$

- Heat conduction

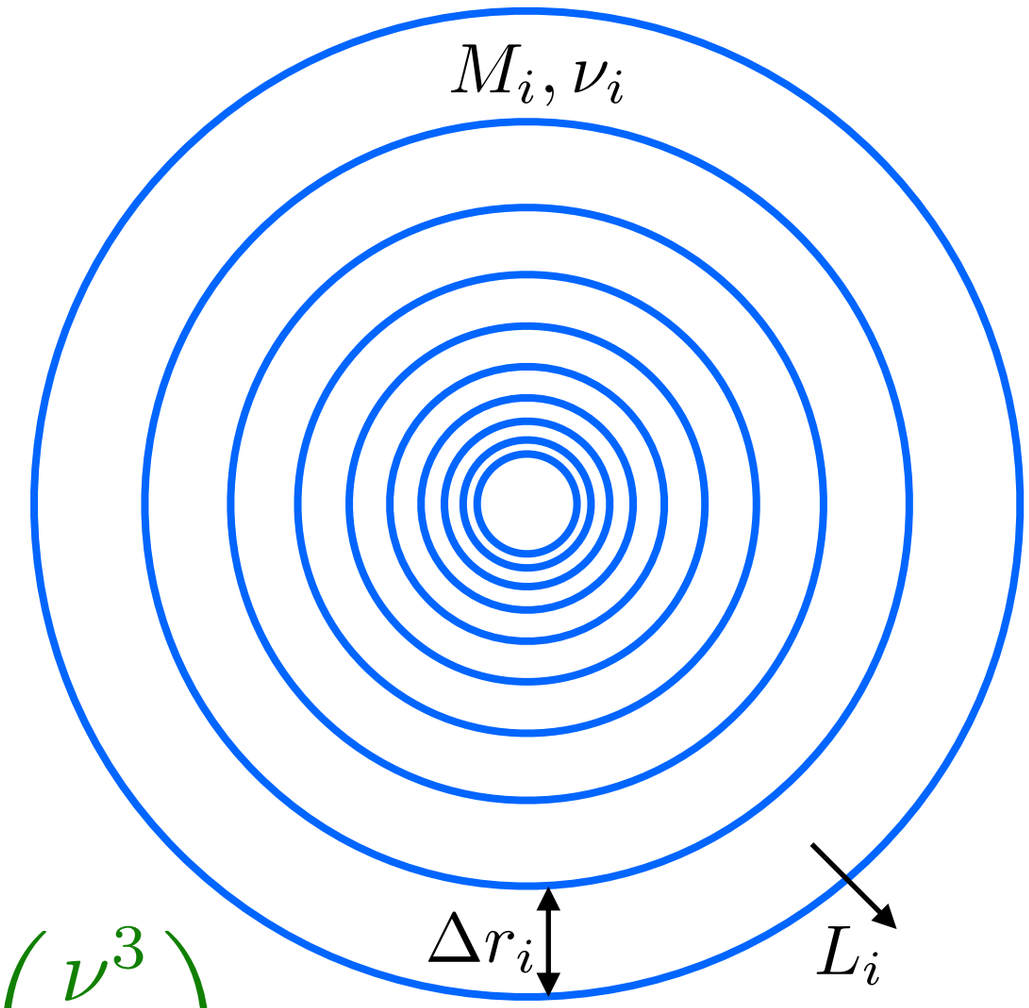
$$\frac{L}{4\pi r^2} = -\kappa \frac{\partial T}{\partial r}$$

Two time scales:

$$t_r = \frac{\lambda_{\rm mfp}}{a\nu} = \frac{\sigma/m}{a\rho\nu}$$

$$t_d = \frac{H}{\nu} = (4\pi\rho G)^{-1/2}$$

Gravothermal Evolution



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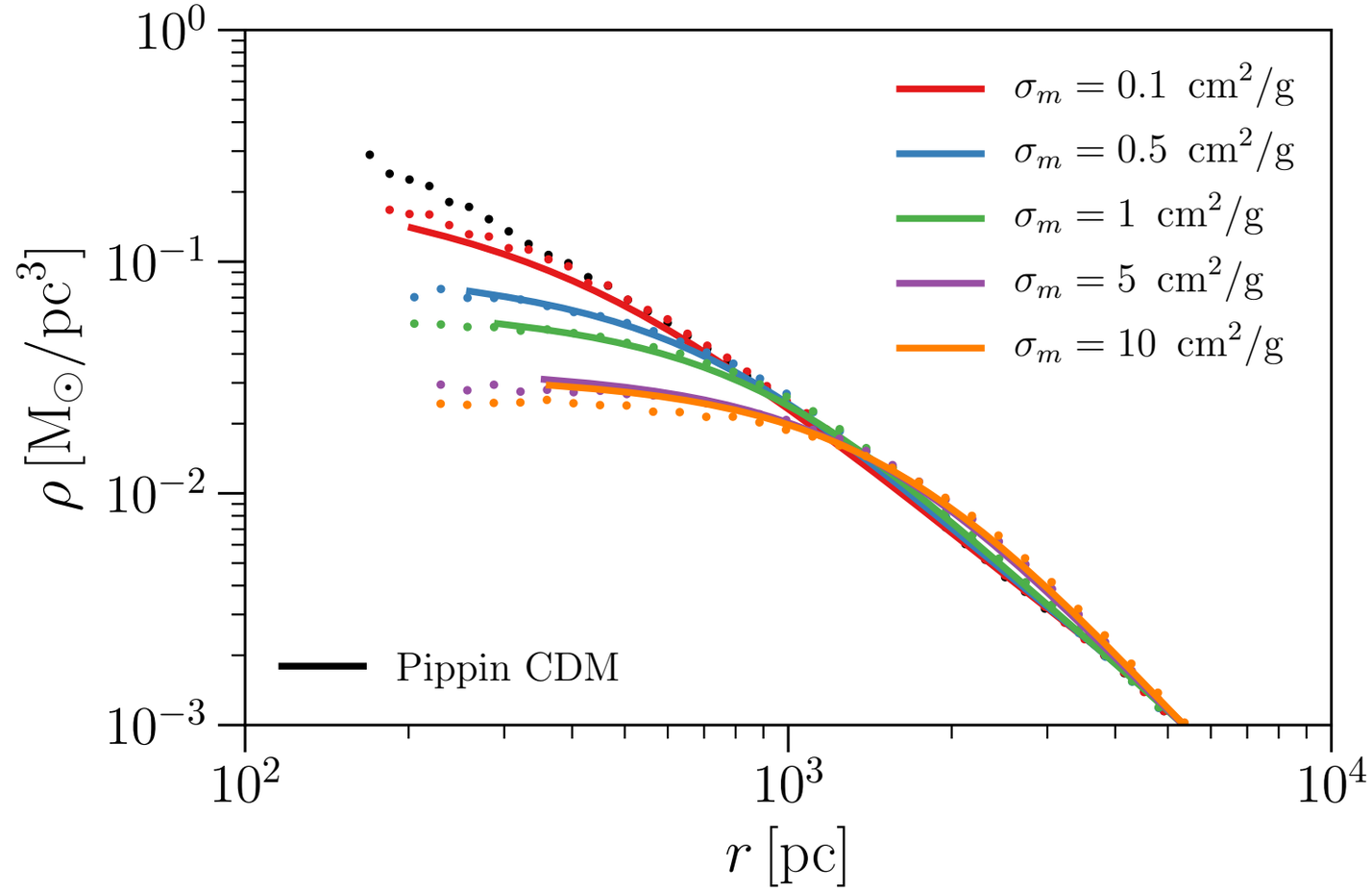
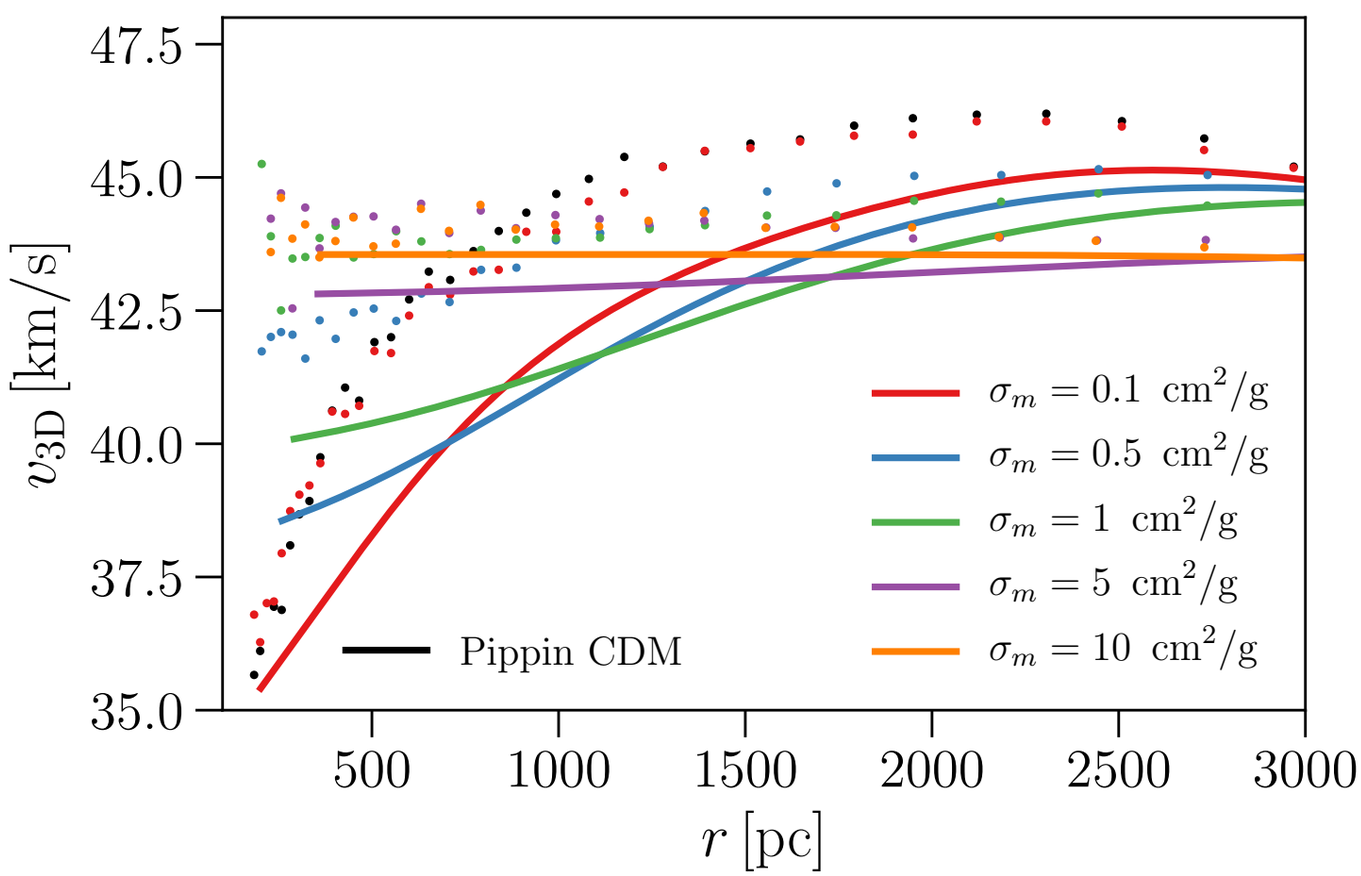
- Heat conduction

$$\frac{L}{4\pi r^2} = -\kappa\frac{\partial T}{\partial r} = -\frac{3}{2}ab\nu\left(\frac{\sigma}{m}\right)\left[a\left(\frac{\sigma}{m}\right)^2 + \frac{b}{C}\frac{4\pi G}{\rho\nu^2}\right]^{-1}\frac{\partial \nu^2}{\partial r}$$

Calibration

Matching densities works well across a range of cross sections



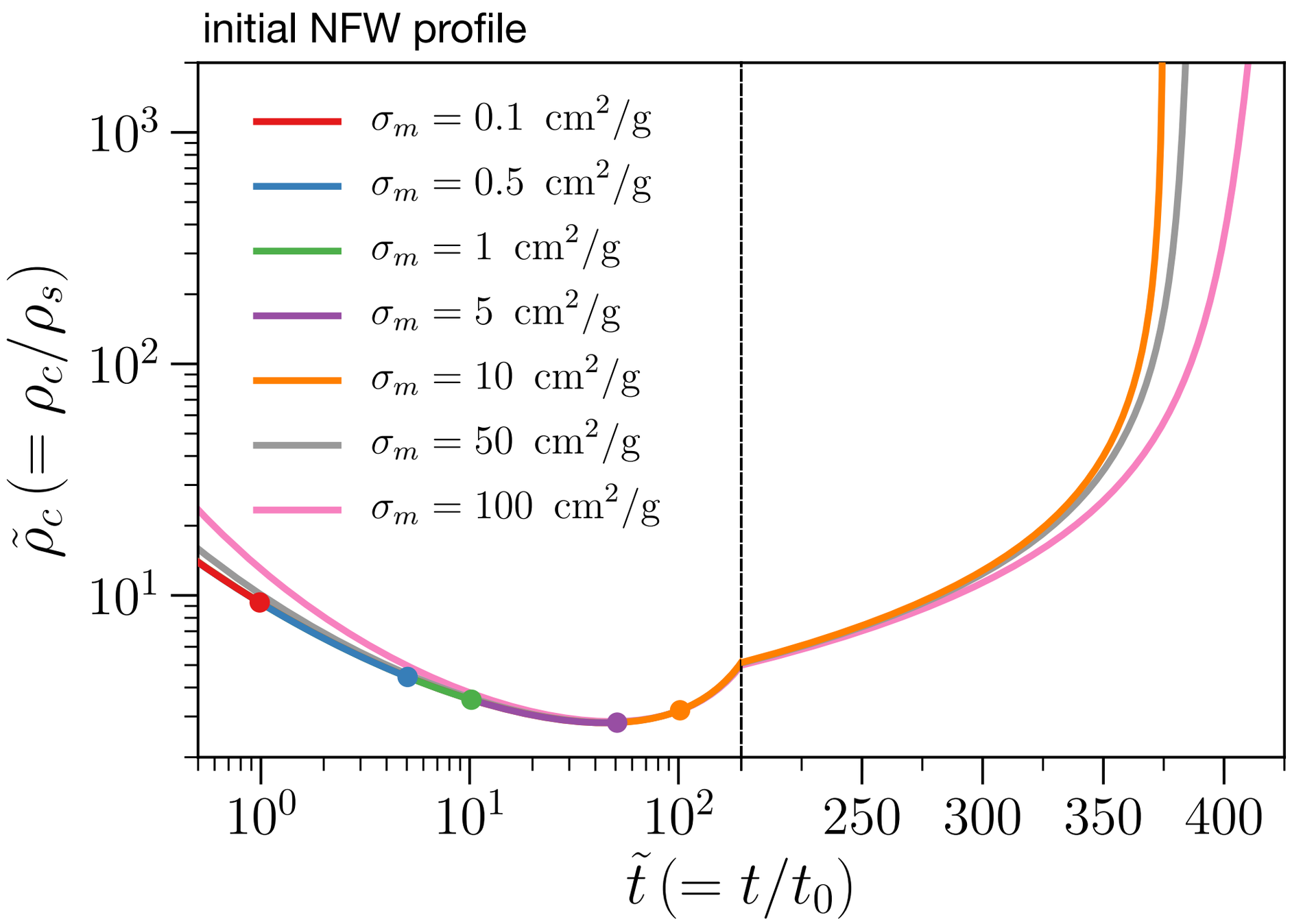


Matching velocity dispersions is more problematic

Simulation reference: *Elbert+, MNRAS (2015)*

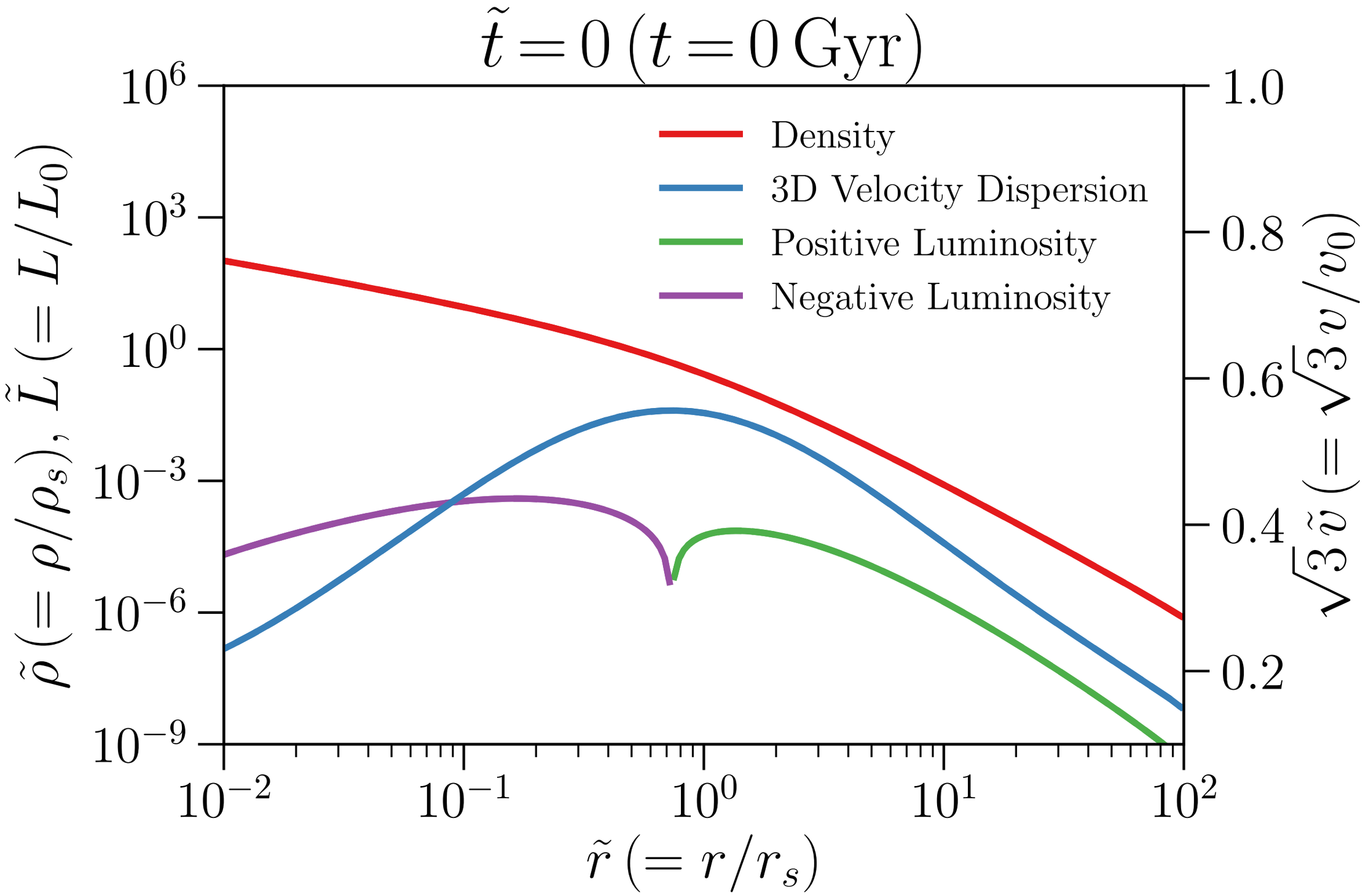
Nishikawa, KB, Kaplinghat (arXiv: 1901.00499)

Central Density



$$t_0^{-1} \sim (\sigma/m) r_s \rho_s^{3/2}$$

Nishikawa, KB, Kaplinghat (arXiv: 1901.00499)



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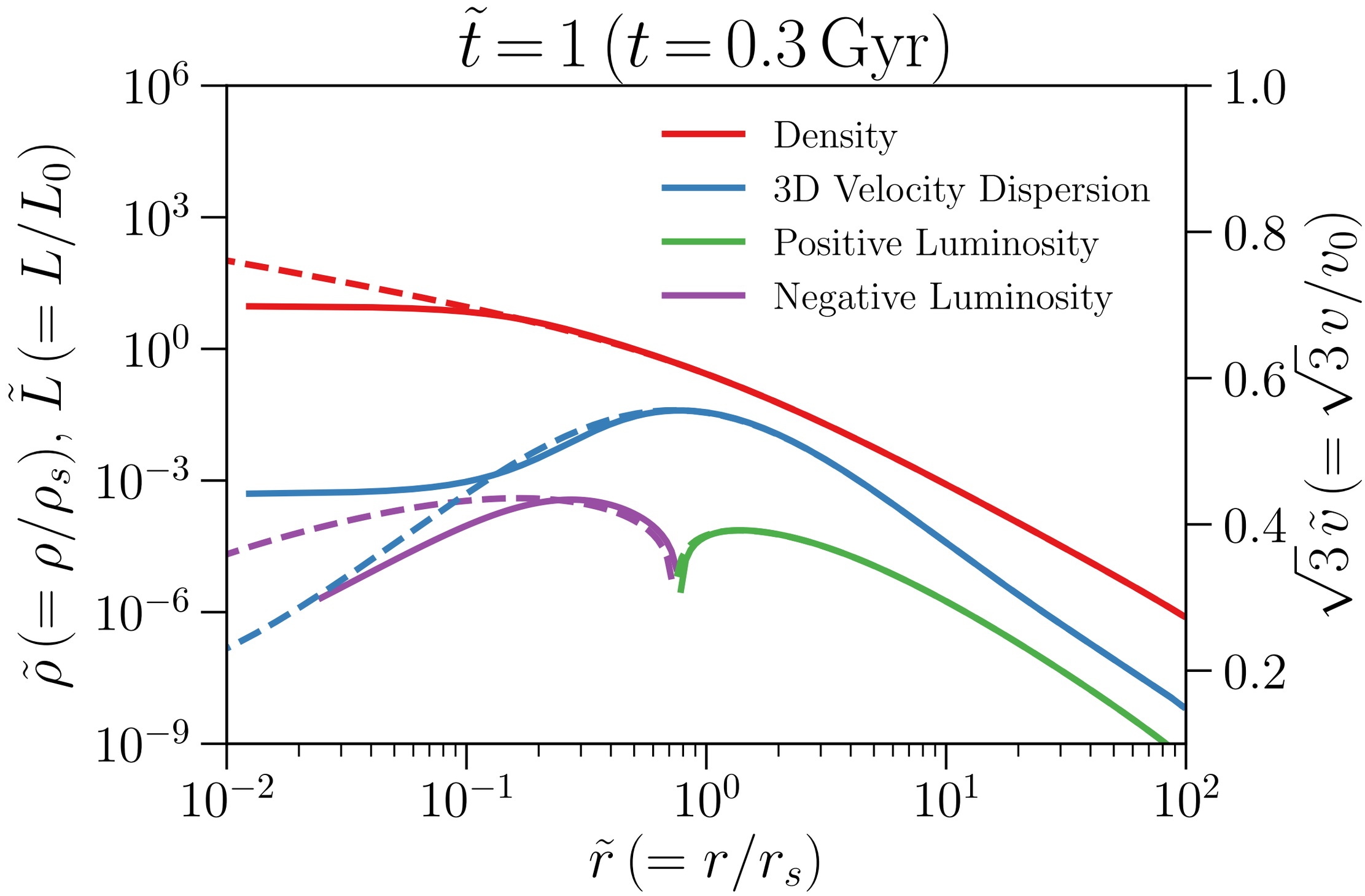

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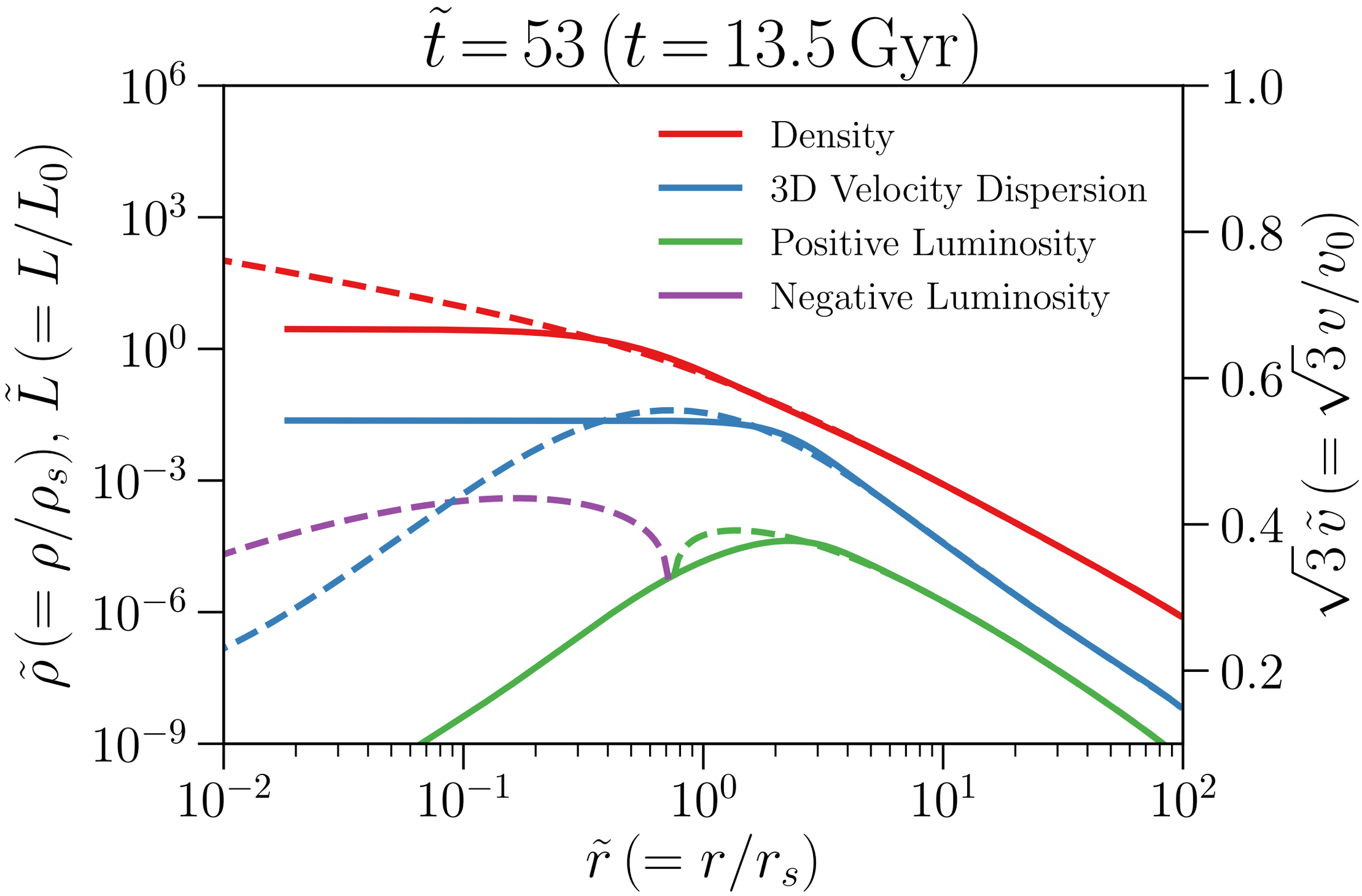

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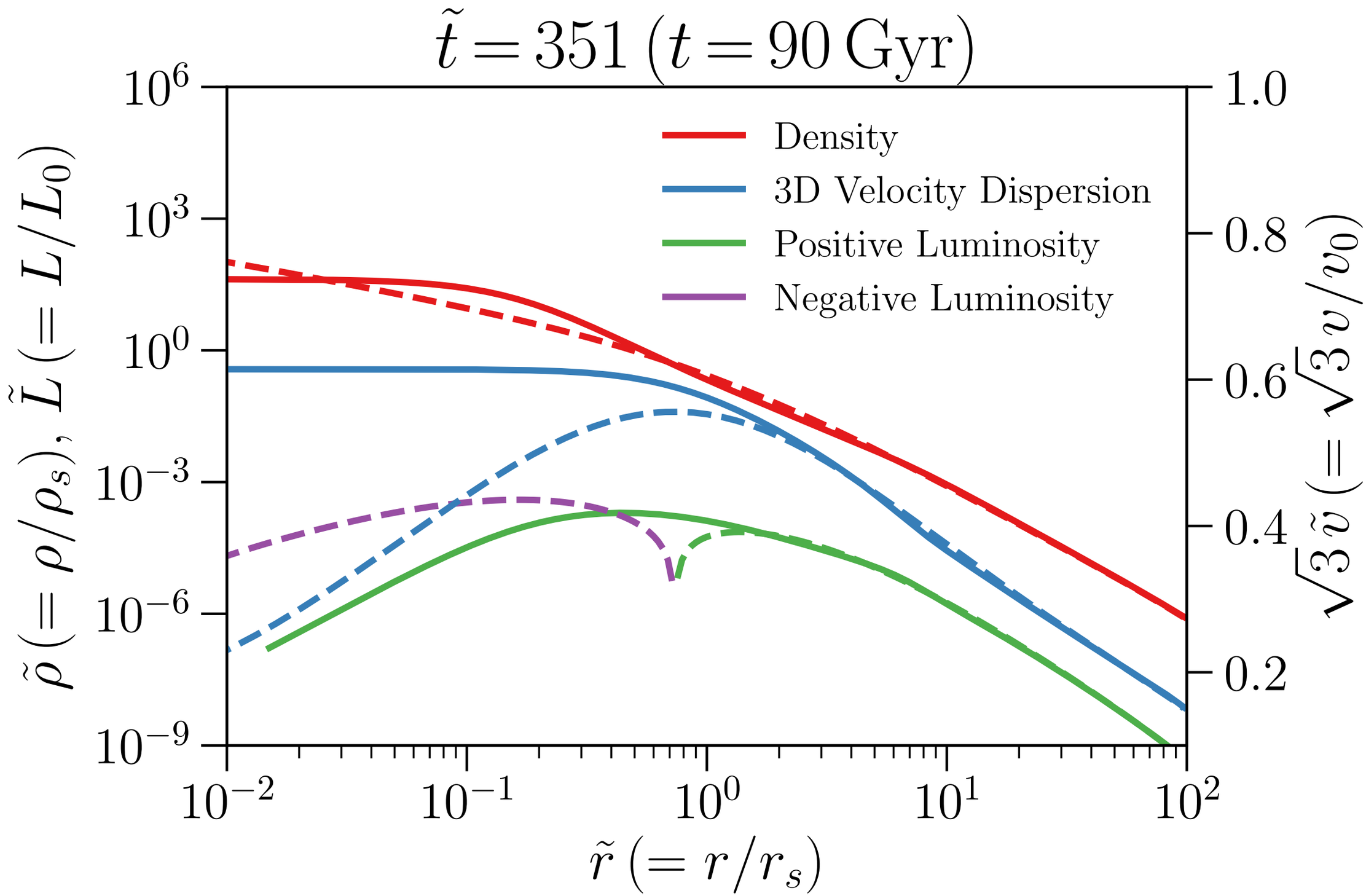

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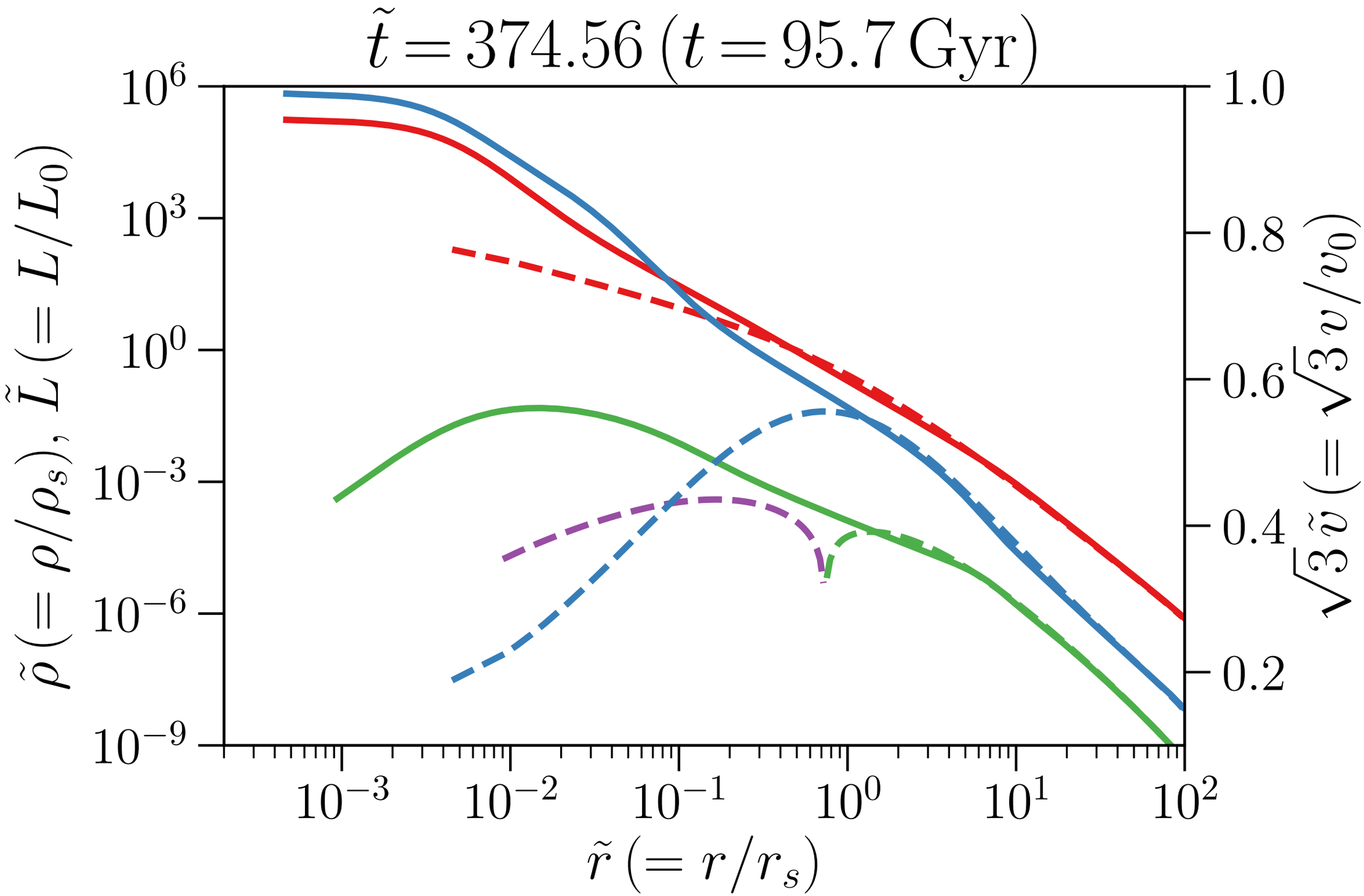
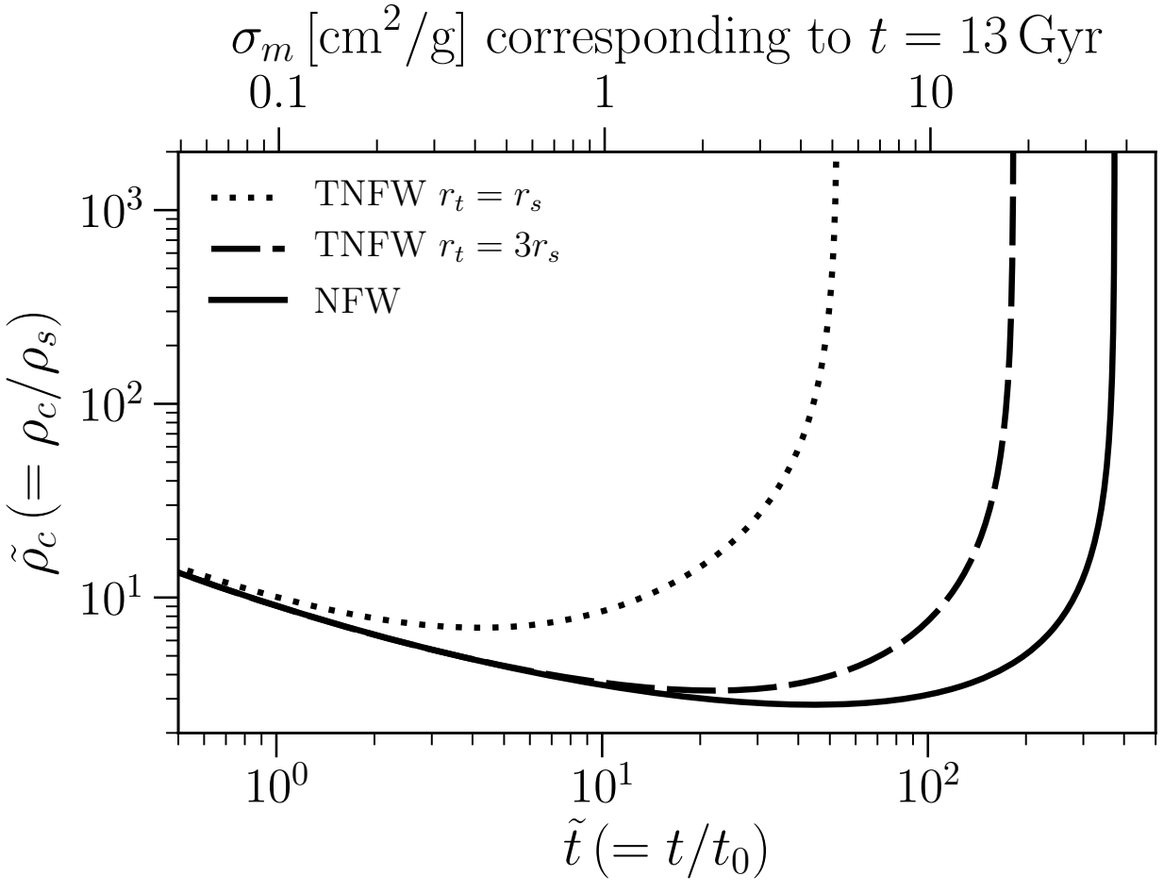


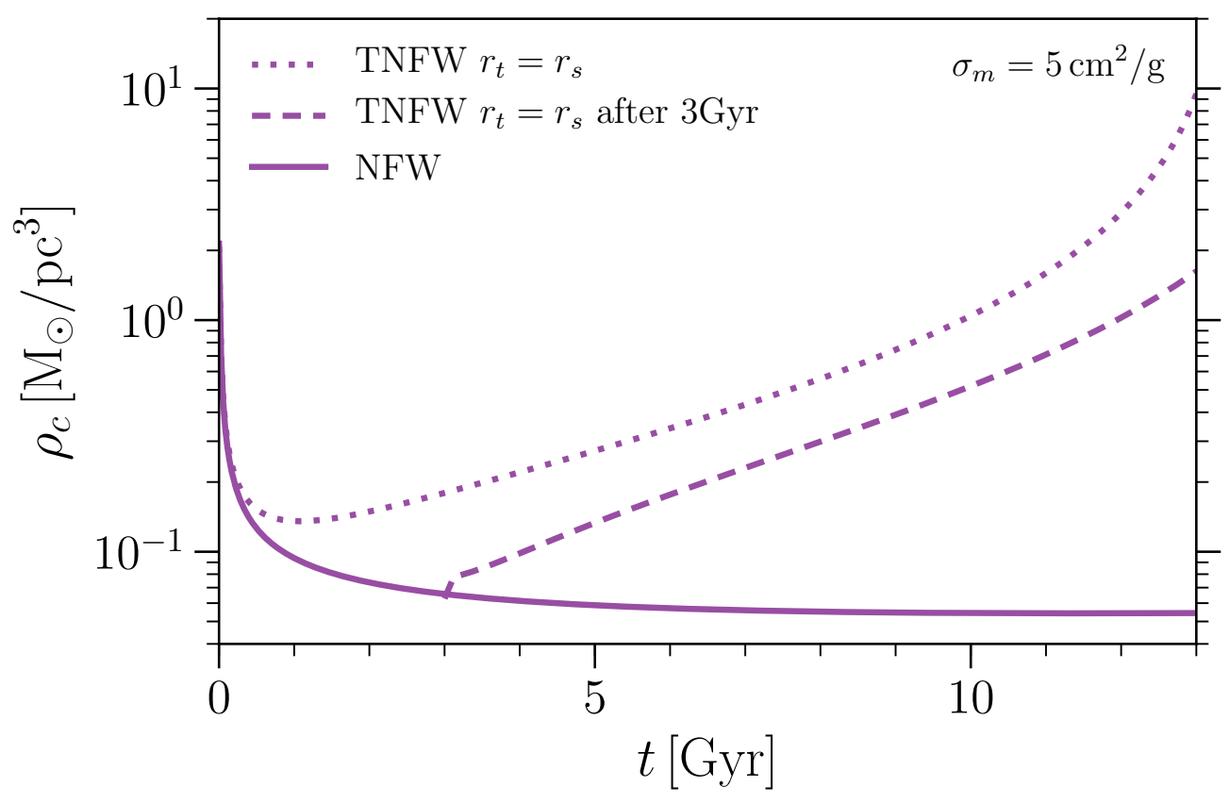
Nishikawa, KB, Kaplinghat (arXiv: 1901.00499)

Tidal Truncation

$$\rho_{\rm NFW} = \frac{\rho_s}{(r/r_s)[1+(r/r_s)^2]}$$

$$\rho_{\rm trunc} = \rho_{\rm NFW} \times \begin{cases} 1 & r < r_t \\ \frac{1}{(r/r_t)^5} & r > r_t \end{cases}$$

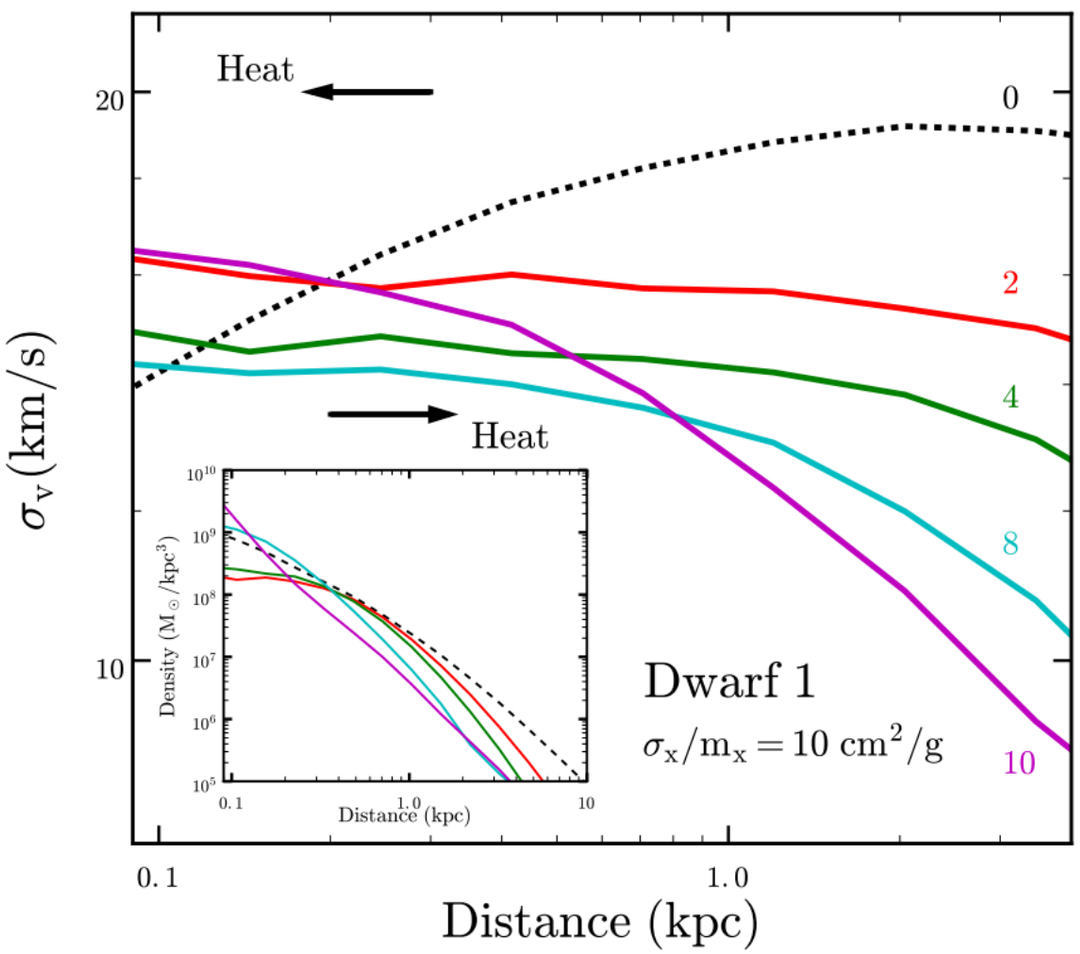




In progress: BH formation

Nishikawa, KB, Kaplinghat (arXiv: 1901.00499)

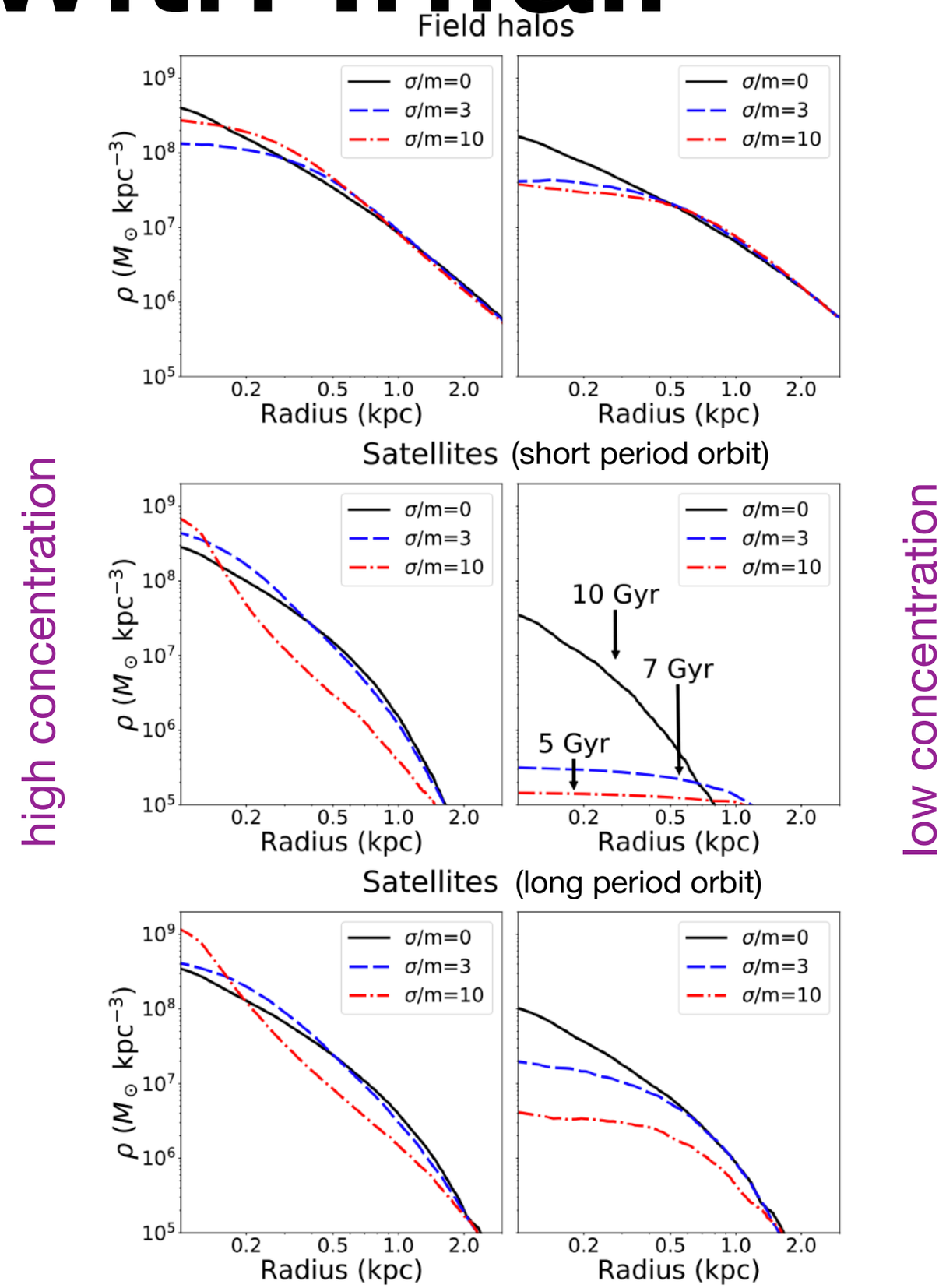
Simulations with Infall



Sameie, Yu, Sales, Vogelsberger, Zavala (1904.07872)

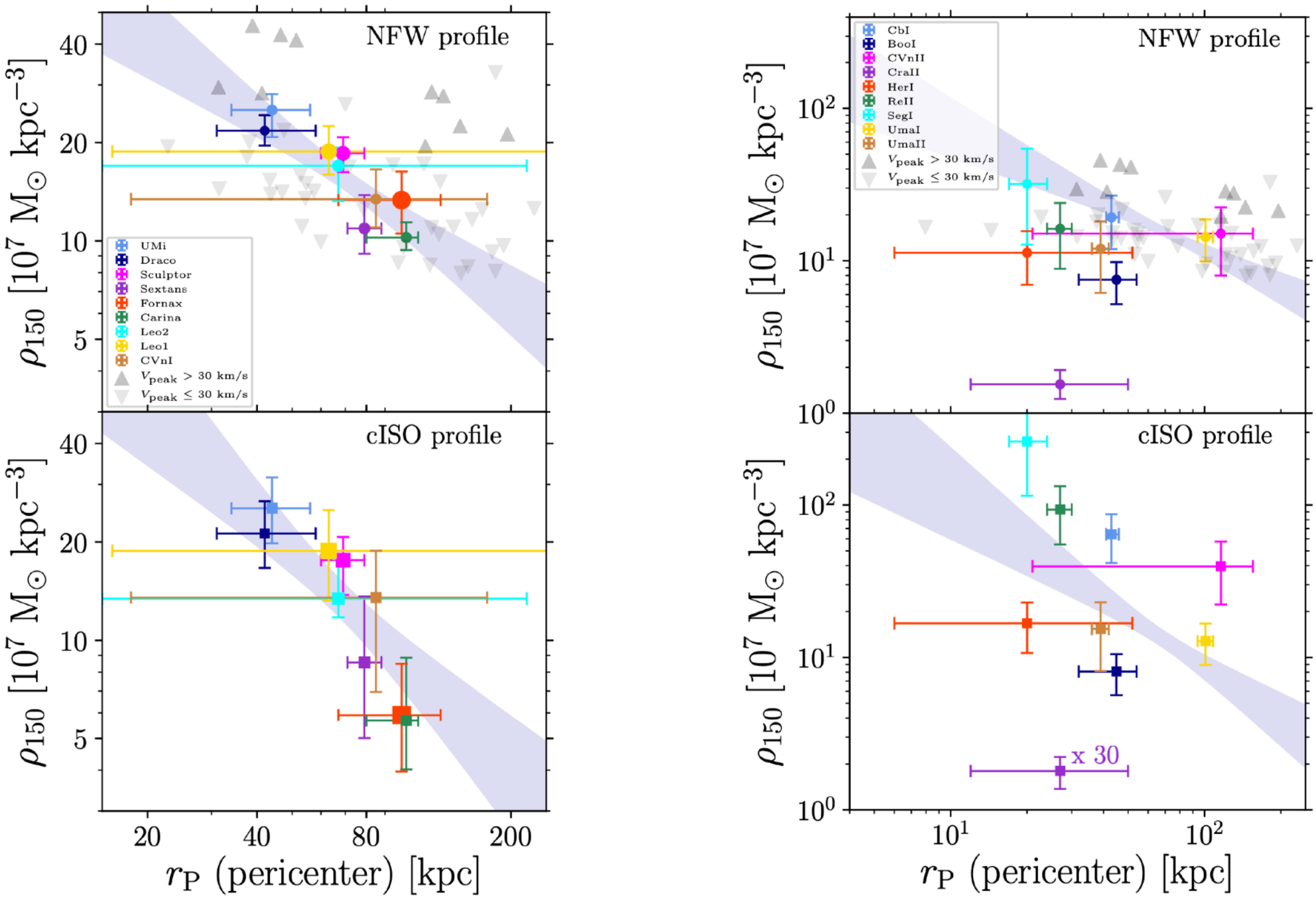
Can obtain wide diversity of halo profiles ("diversity problem")

See also:
Zavala, Lovell, Vogelsberger, Burger (1904.09998)



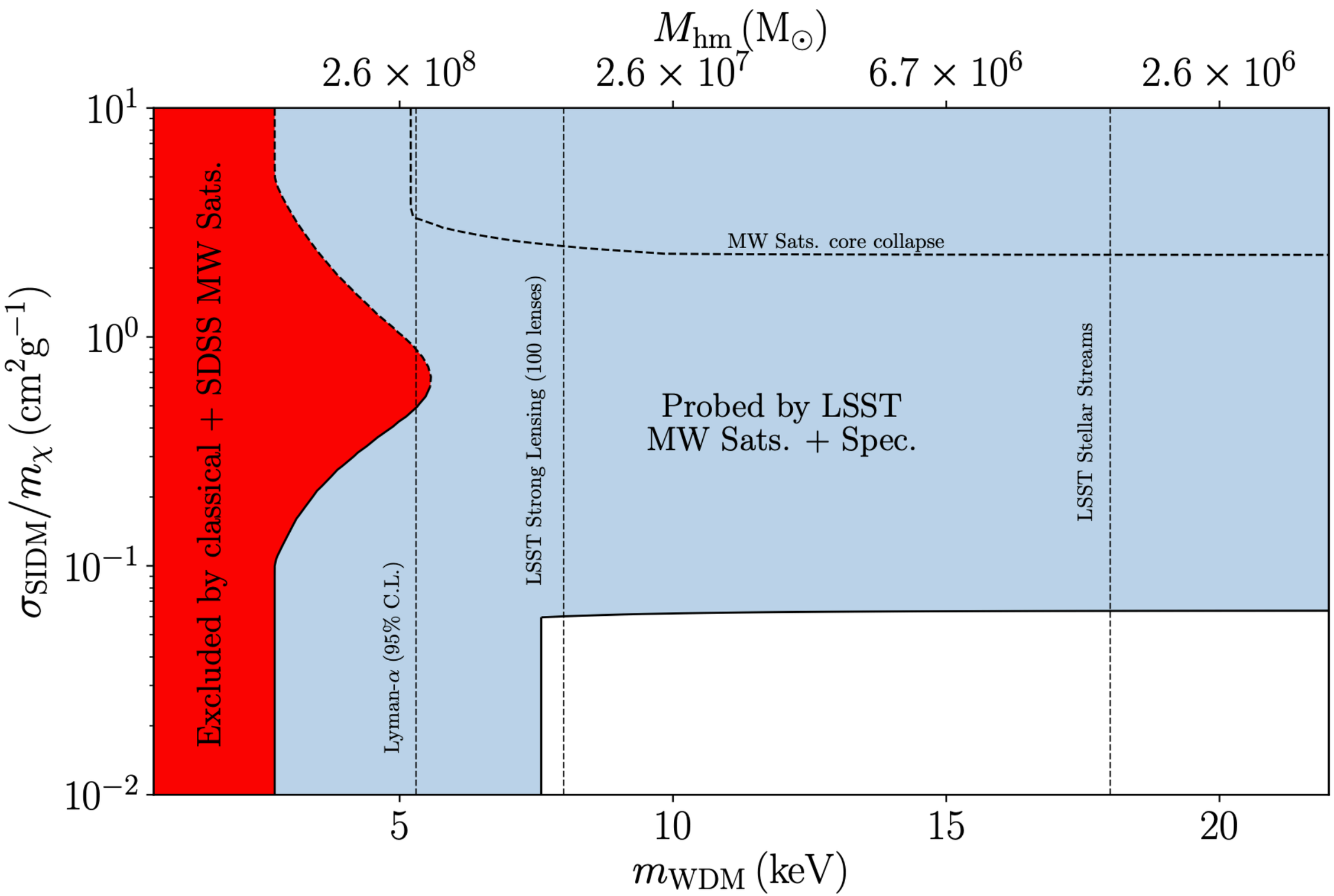
Kahlhoefer, Kaplinghat, Slatyer, Wu (1904.10539)

TBTF Revisited



Kaplinghat, Valli, Yu (1904.04939)

LSST Connection



Drlica-Wagner+ (arXiv: 1902.01055)