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Dark Matter and the satellites of the Milky Way

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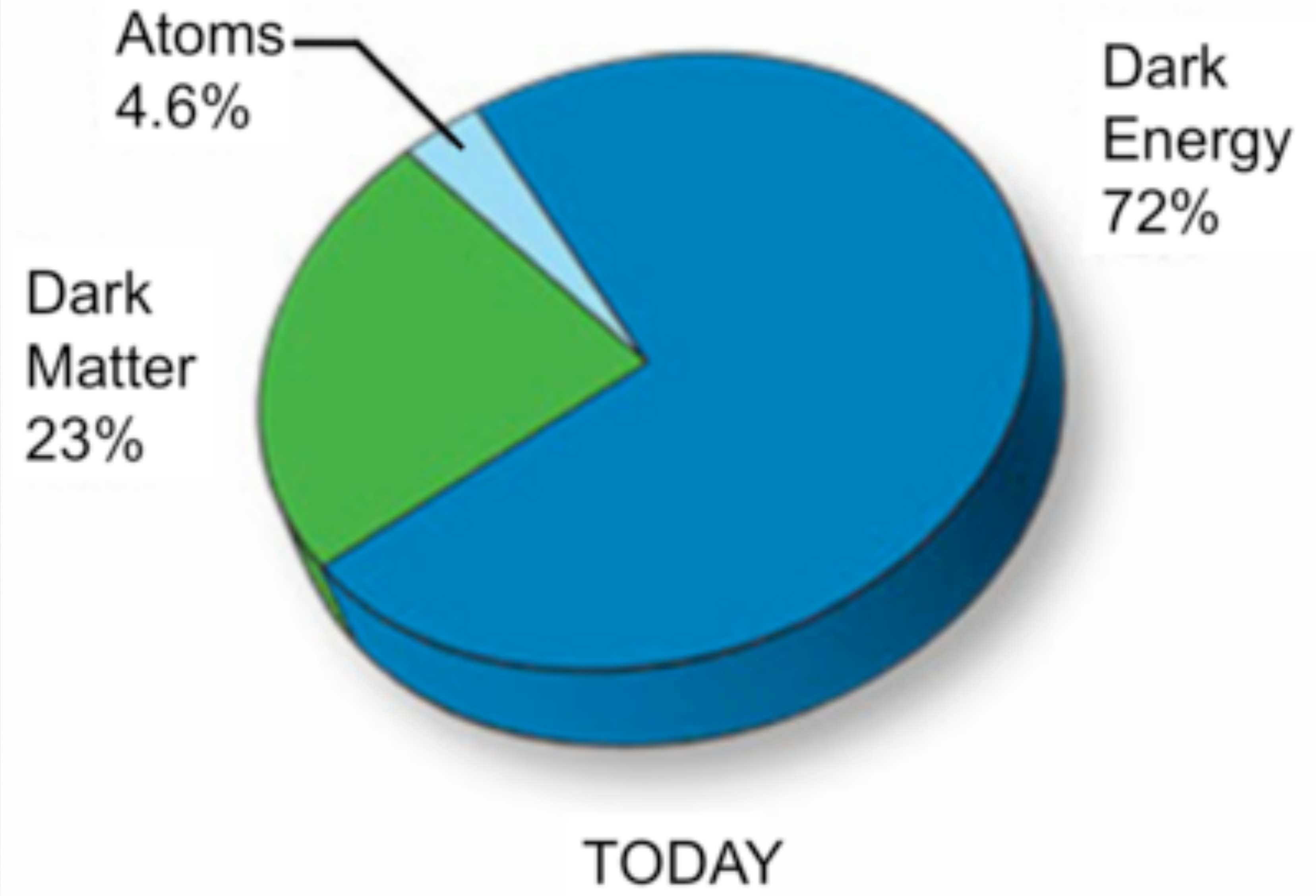
In collaboration with M. Regis and M. Taoso

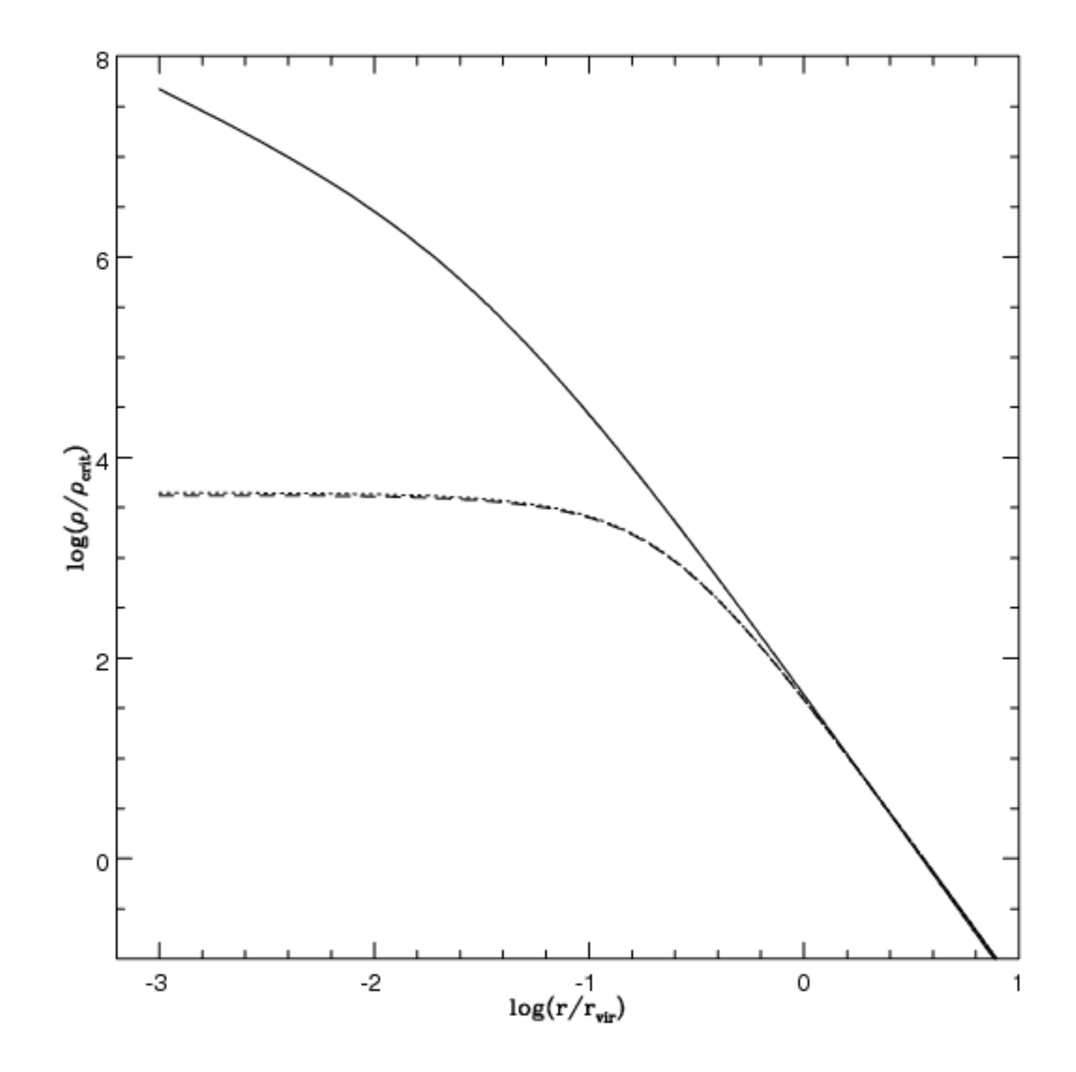
Cold Dark Matter - Self-Interacting Dark Matter

- Cold dark matter is a success on large scales …
- Key on the standard cosmological model…



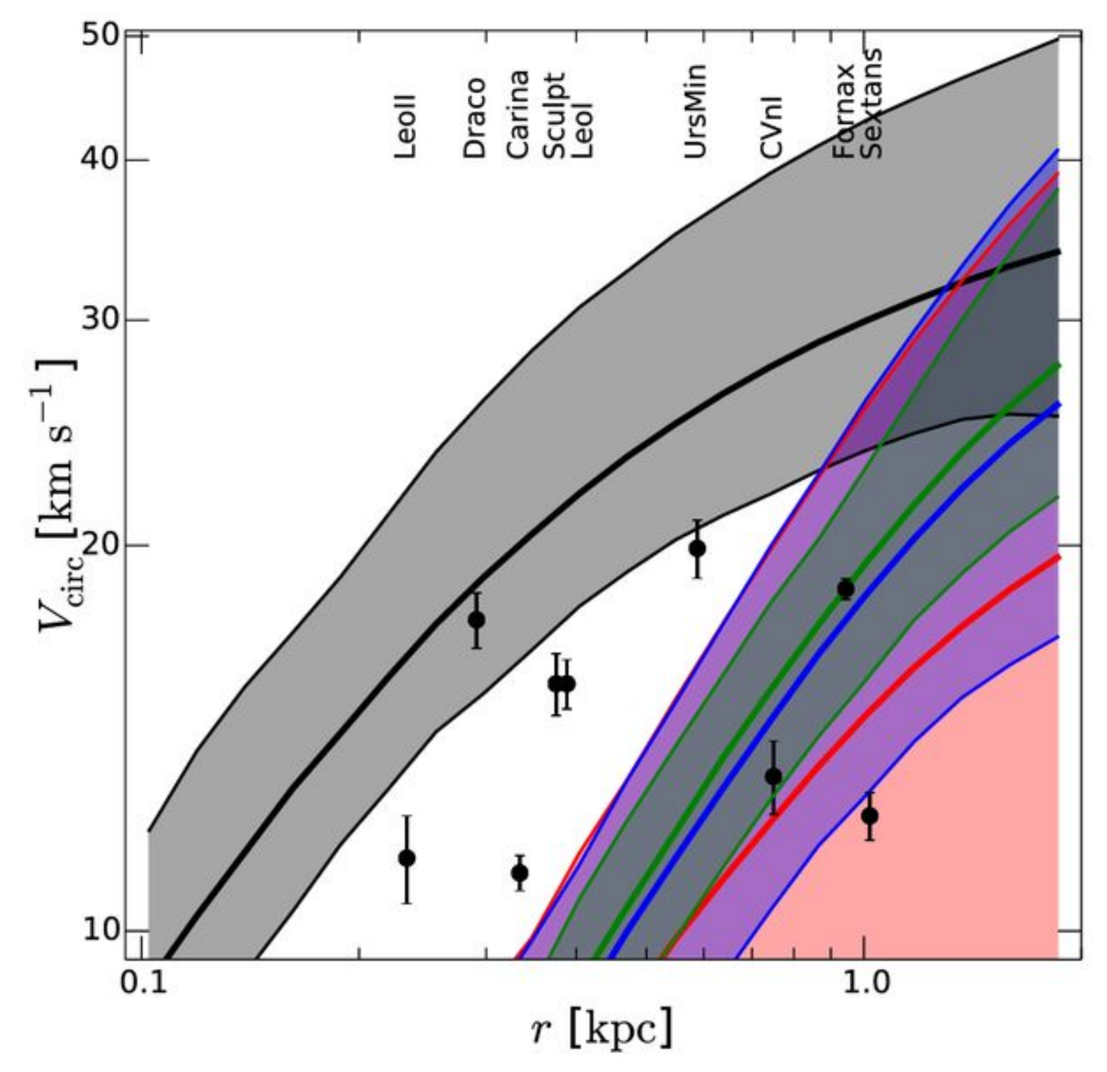
https://astronomy.swin.edu.au/cosmos/d/Dark+Matter

Small Scales



Cusp vs Core

Del Popolo, Astrophys.J.698(2009)



Too big too fail

Vogelsberger et at. 2016

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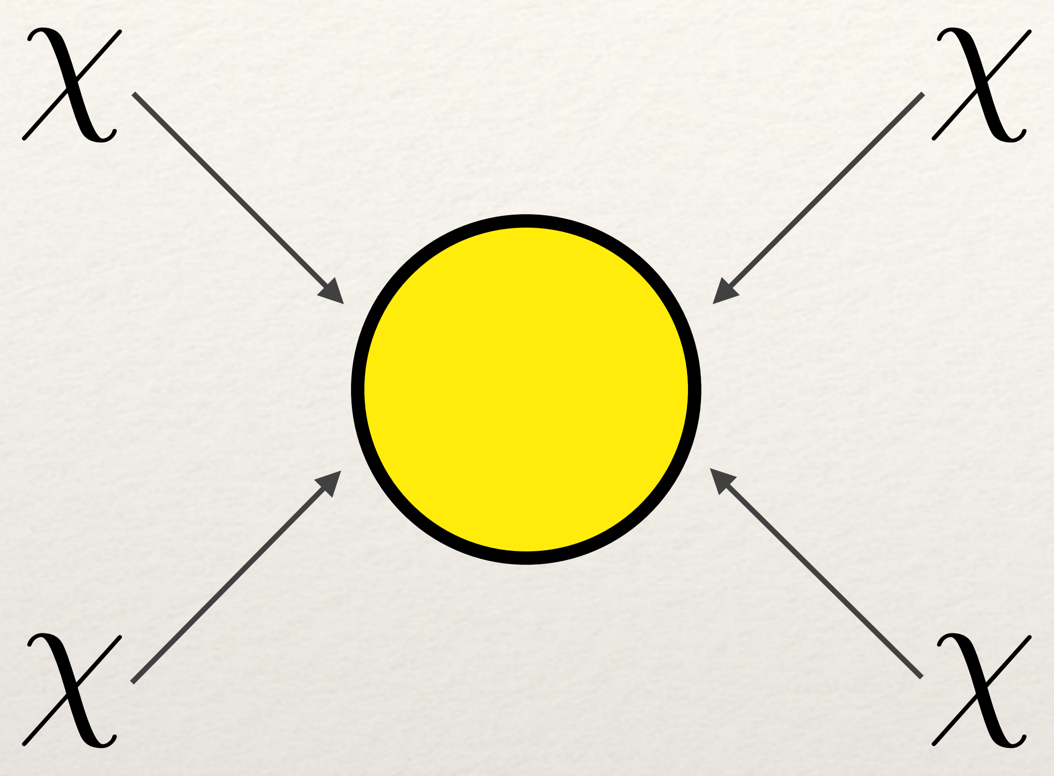
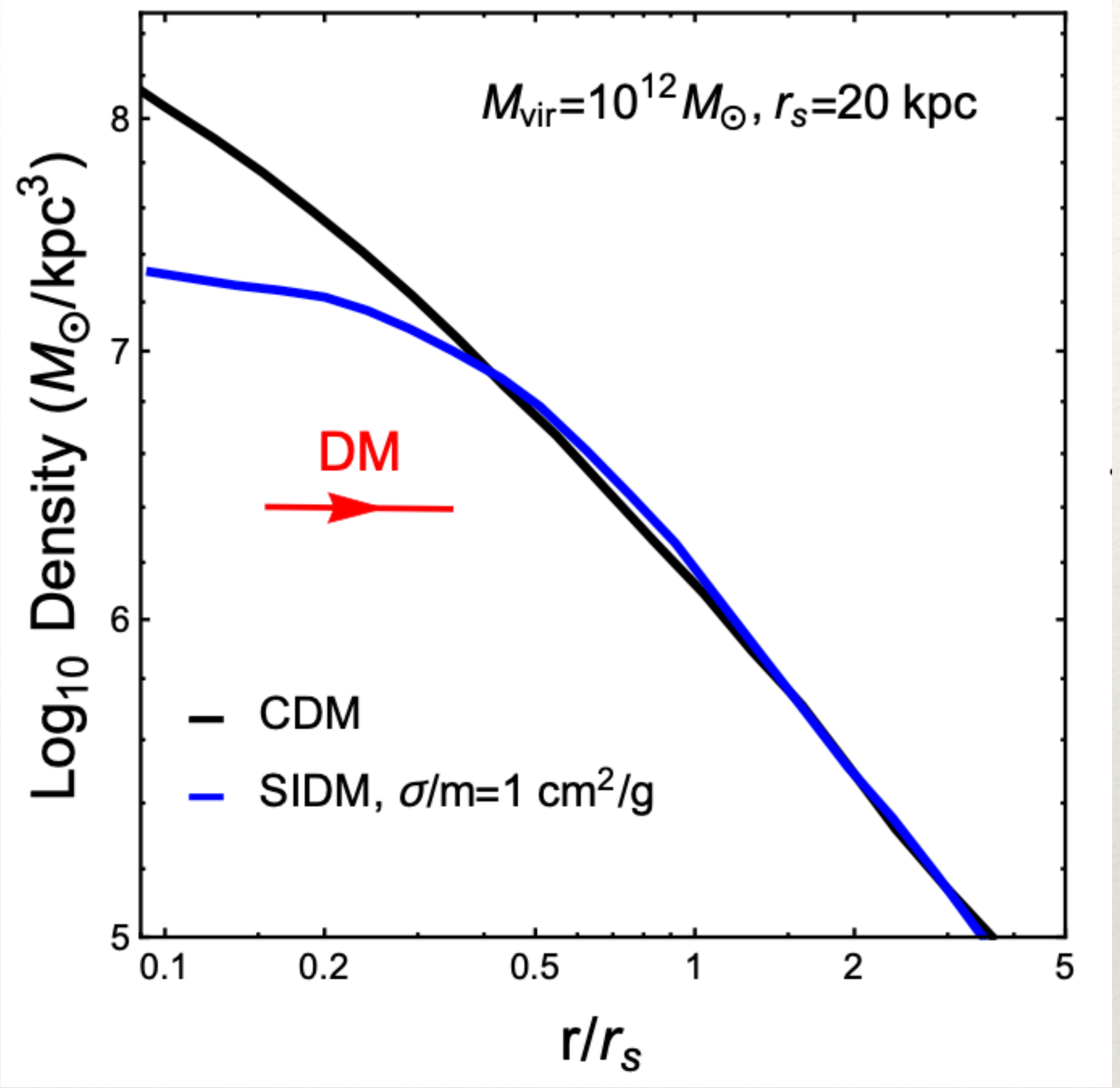
SIDM proposal



$\sigma/m \sim (0.5 - 500)\mathrm{cm}^2\mathrm{g}^{-1}$

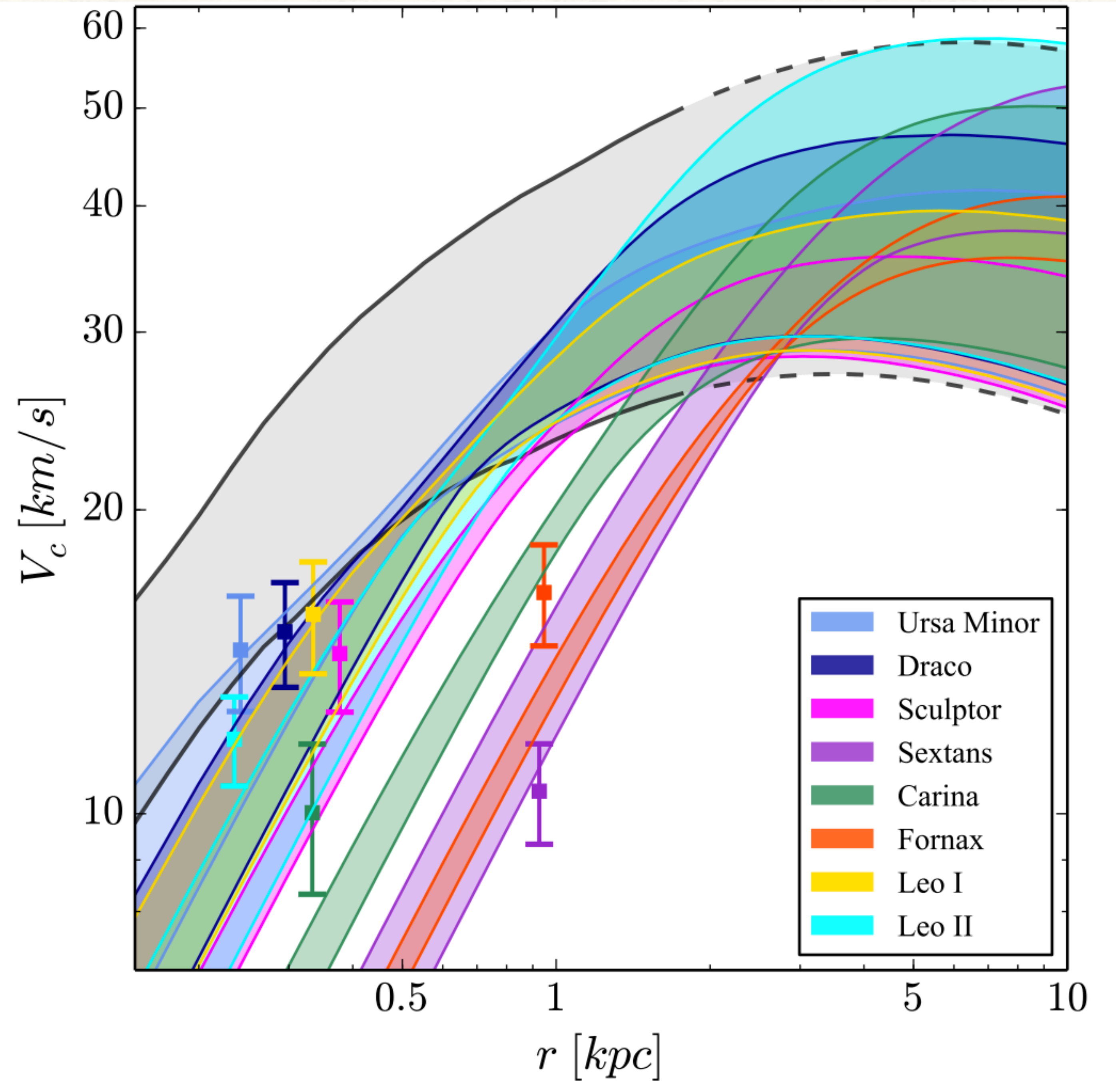
Spergel and Steinhardt '99

In this work: test SIDM
Dwarf galaxies are ideal laboratories
Dark matter dominated!



Tulin S. B. And Yu H. 2017

Scatterings can turn a cusp into a core



Valli M. And Yu H. 2018

Can solve the too big too fail ?

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The model

- The internal dynamics of a dwarf galaxy is studied through the kinematics of stellar population

The first moment of the Boltzmann equation

$$\frac{\partial(\nu(r)\sigma_r^2(r))}{\partial r} + \frac{2\beta_{\rm ani}(r)\sigma_r^2(r)}{r} = -\nu(r)\frac{\partial\phi_{\rm DM}}{\partial r}$$

Stellar density Distribution

Radial velocity Distribution

Stellar Orbital Anisotropy

DM potential

Only the line of sight velocitiy distribution are observed !

$$\sigma^2_{\rm l.o.s}(R) = \frac{2}{\Sigma(R)}\int_R^\infty dr\left(1-\beta_{\rm ani}(r)\frac{R^2}{r^2}\right)\frac{\nu(r)\sigma_r^2(r)}{\sqrt{1-R^2/r^2}}$$

DM model: SIDM + CDM profile

Isothermal profile

$$h''(x) + 2\frac{h'(x)}{x} = -e^{h(x)}$$

$$h(x) \equiv \ln\left(\rho(x)/\rho_0\right) \qquad x \equiv \sqrt{4\pi G_n\rho_o}\frac{r}{\sigma_o}$$

NFW profile

$$\rho(r) = \frac{\rho_s}{(r/rs)(1+r/rs)^2}$$

Matching condition!

$$\frac{M_{\rm iso}(r_1)}{4\pi r_1^2\rho_{iso}(r_1)} = \frac{M_{\rm NFW}(r_1)}{4\pi r_1^2\rho_{NFW}(r_1)} = R$$

Three free parameters!

Demanding 1 collision over the dwarfs lifetime

CDM and SIDM

$$\sigma/m_\chi = \frac{\sqrt{\pi}}{4\sigma_0\rho(r_1)t_{\rm age}}$$

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Analysis- pyGravSphere (Genina A. et al 2020)

- Python wrapper based on the gravsphere.c code (Read J. and Steger P. 2017)

$$\sigma^2_{\mathrm{l.o.s}}(R) = \frac{2}{\Sigma(R)} \int_R^{\infty} dr \left(1 - \beta_{\mathrm{ani}}(r)\frac{R^2}{r^2}\right) \frac{\nu(r)\sigma_r^2(r)}{\sqrt{1 - R^2/r^2}}$$

→ Mass-anisotropy degeneracy

- Using higher moment of the Boltzmann equation to break the mass-anisotropy degeneracy
- MCMC-Based on the ensemble sampler emcee (python)

Modify to introduce SIDM + CDM

Only two DM profiles!

$$\rho(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)^{\gamma}\left(1+\left(\frac{r}{r_s}\right)^{\alpha}\right)^{\frac{\beta-\gamma}{\alpha}}}$$

$$\rho(r) = \begin{cases} \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma_0} & r < r_0 \\ \rho_0 \left(\frac{r}{r_{j+1}}\right)^{-\gamma_{j+1}} \prod_0^{n<j+1} \left(\frac{r_{n+1}}{r_n}\right)^{-\gamma_{n+1}} & \end{cases}$$

New ingredient: concentration relation for CDM

$$c_v = c_0[1 + b\log x_{\mathrm{sub}}]\left[1 + \sum_{i=1}^{3}\left[a_i \log\left(\frac{V_{\mathrm{max}}}{10\mathrm{km\ s}^{-1}}\right)\right]\right]$$

Moliné A. Et al. 2017

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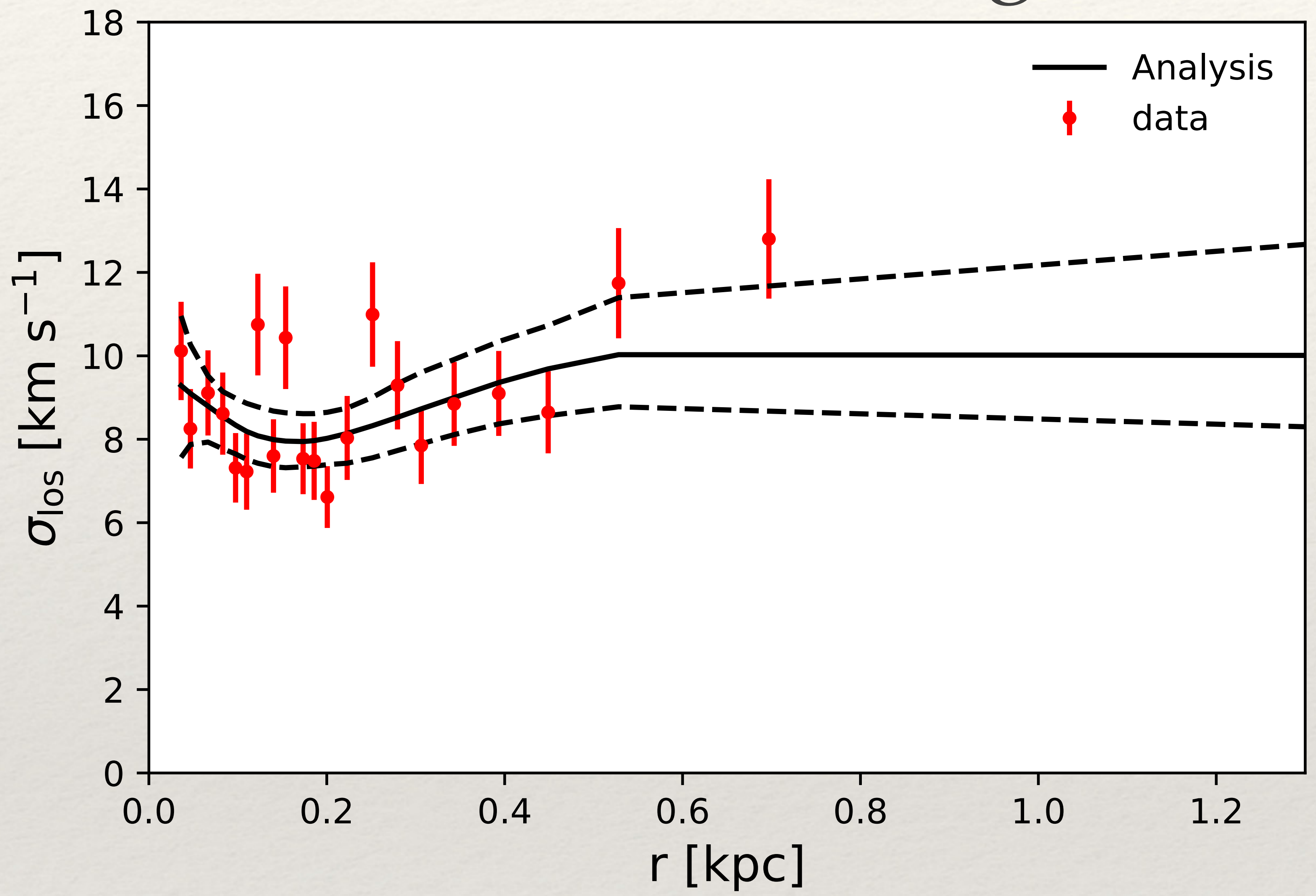
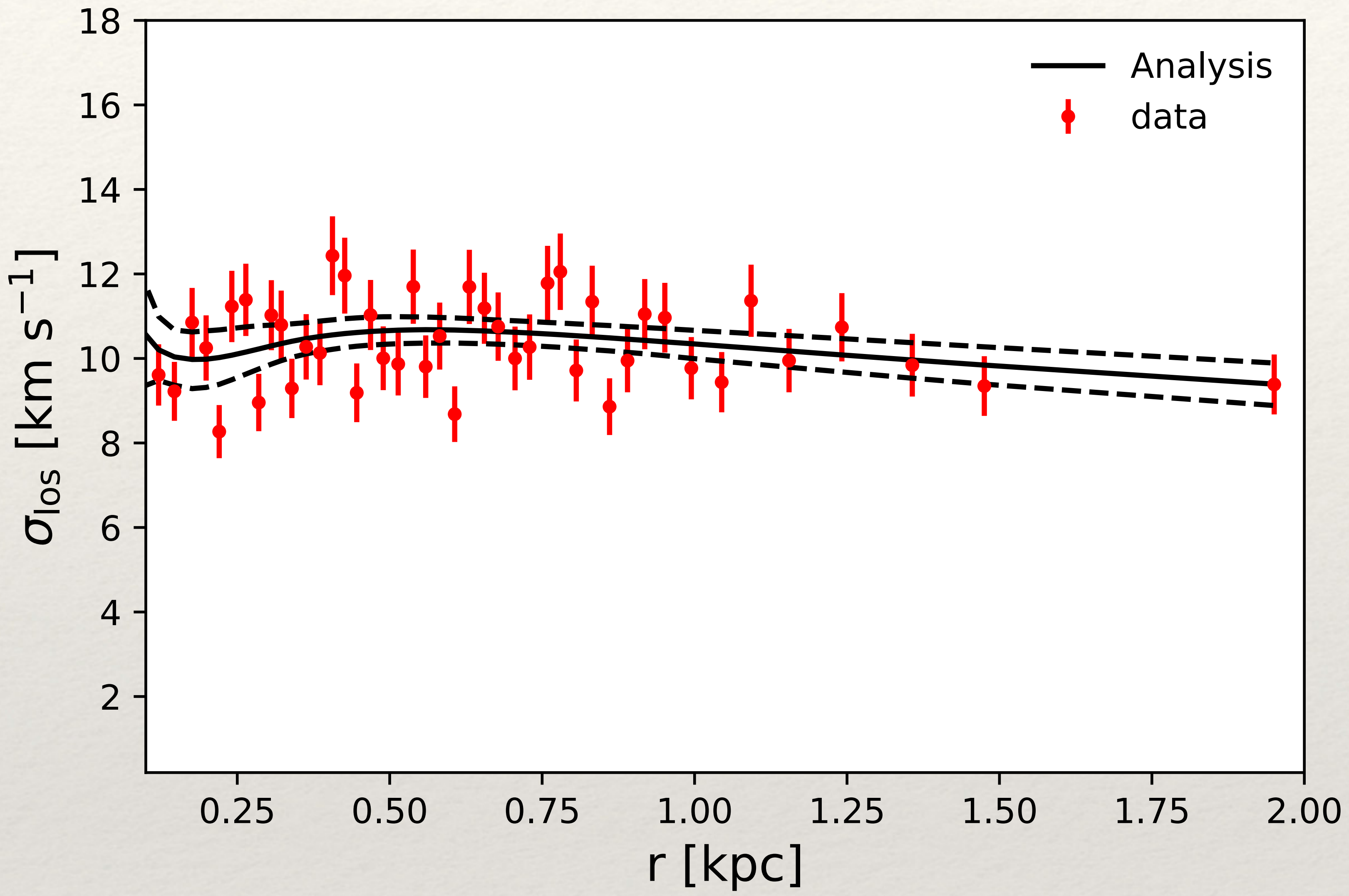
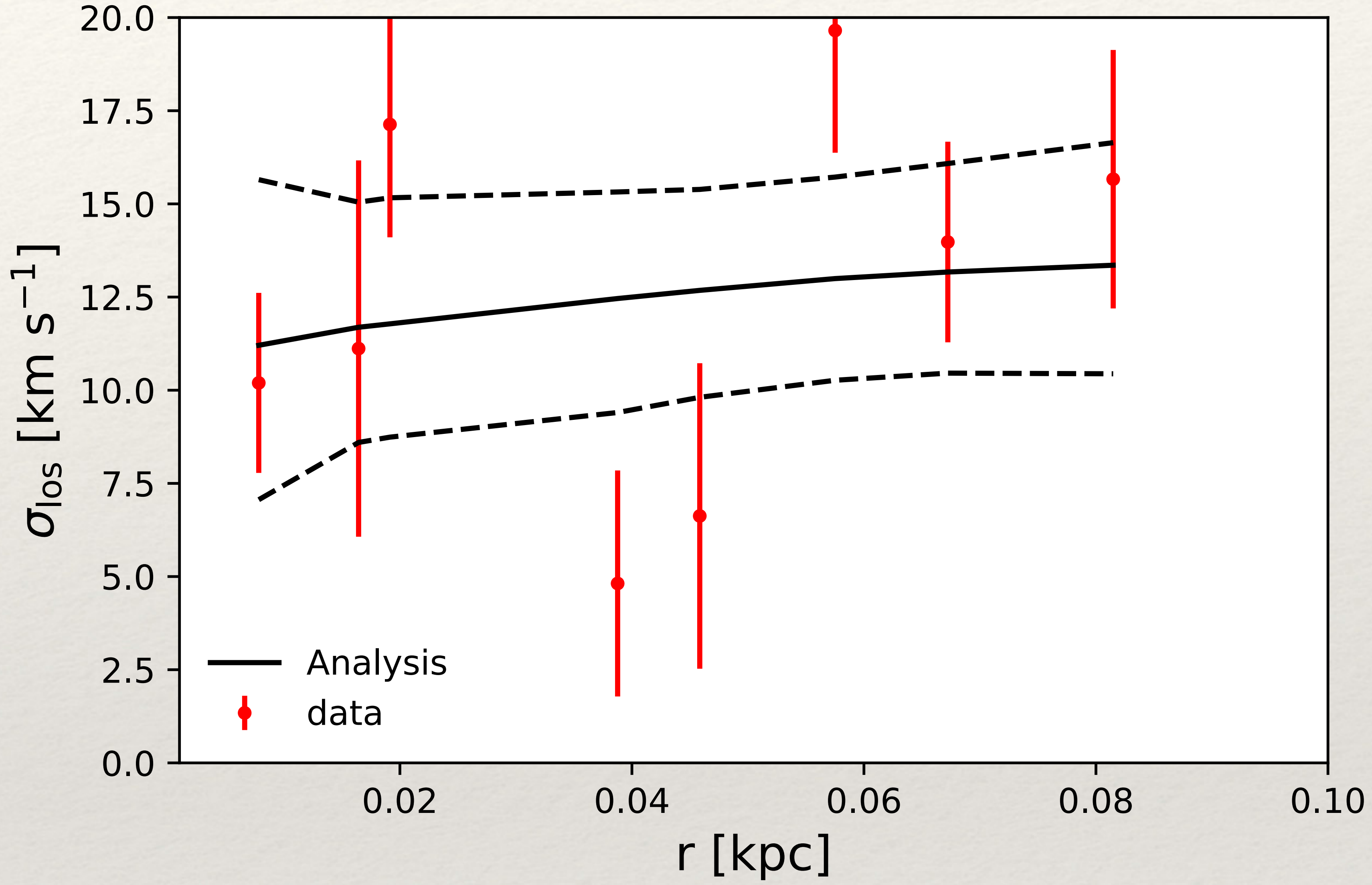
Results for tested dwarfs

- Draco, Fornax, Segue1







$$\sigma/m_\chi = 0.440^{+0.135}_{-0.106}\ \ \mathrm{cm^2 g^{-1}}$$

$$\sigma/m_\chi = 1.498^{+3.304}_{-1.137}\ \mathrm{cm^2 g^{-1}}$$

$$\sigma/m_\chi = 0.104^{+0.111}_{-0.099}\ \ \mathrm{cm^2 g^{-1}}$$

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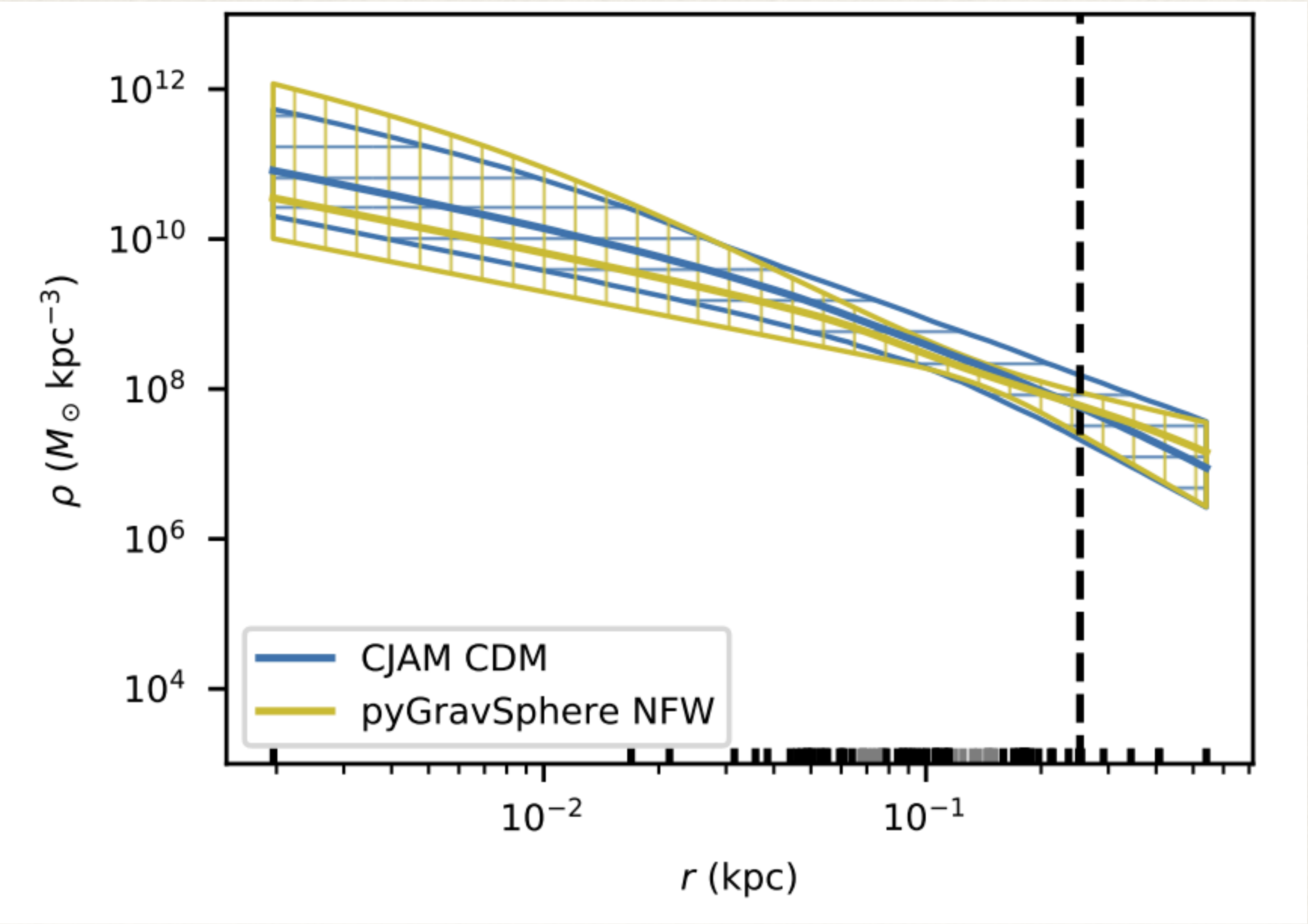
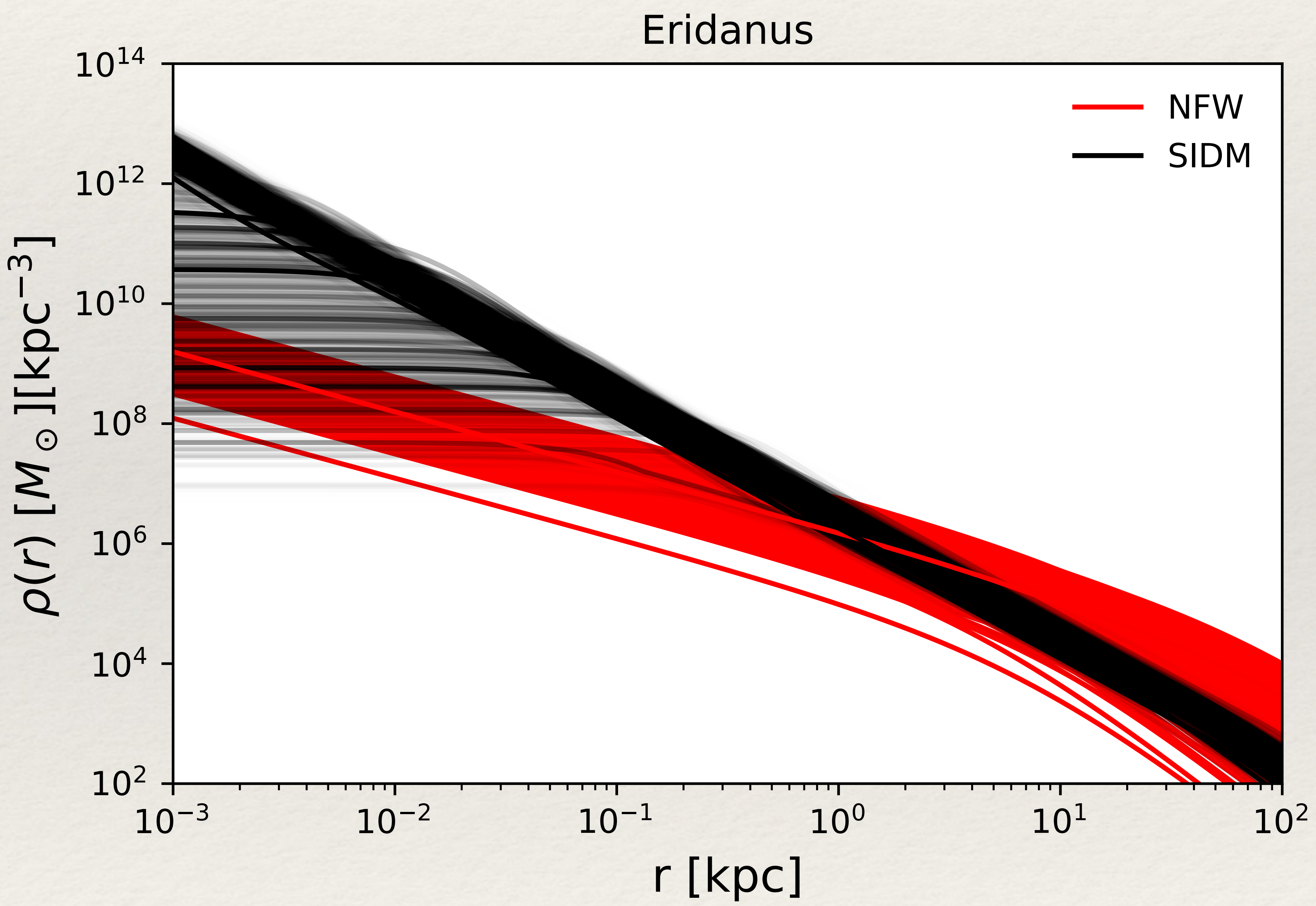
Eridanus

- Zoutendijk et al. 2021 found evidence for CDM over SIDM (annihilating)

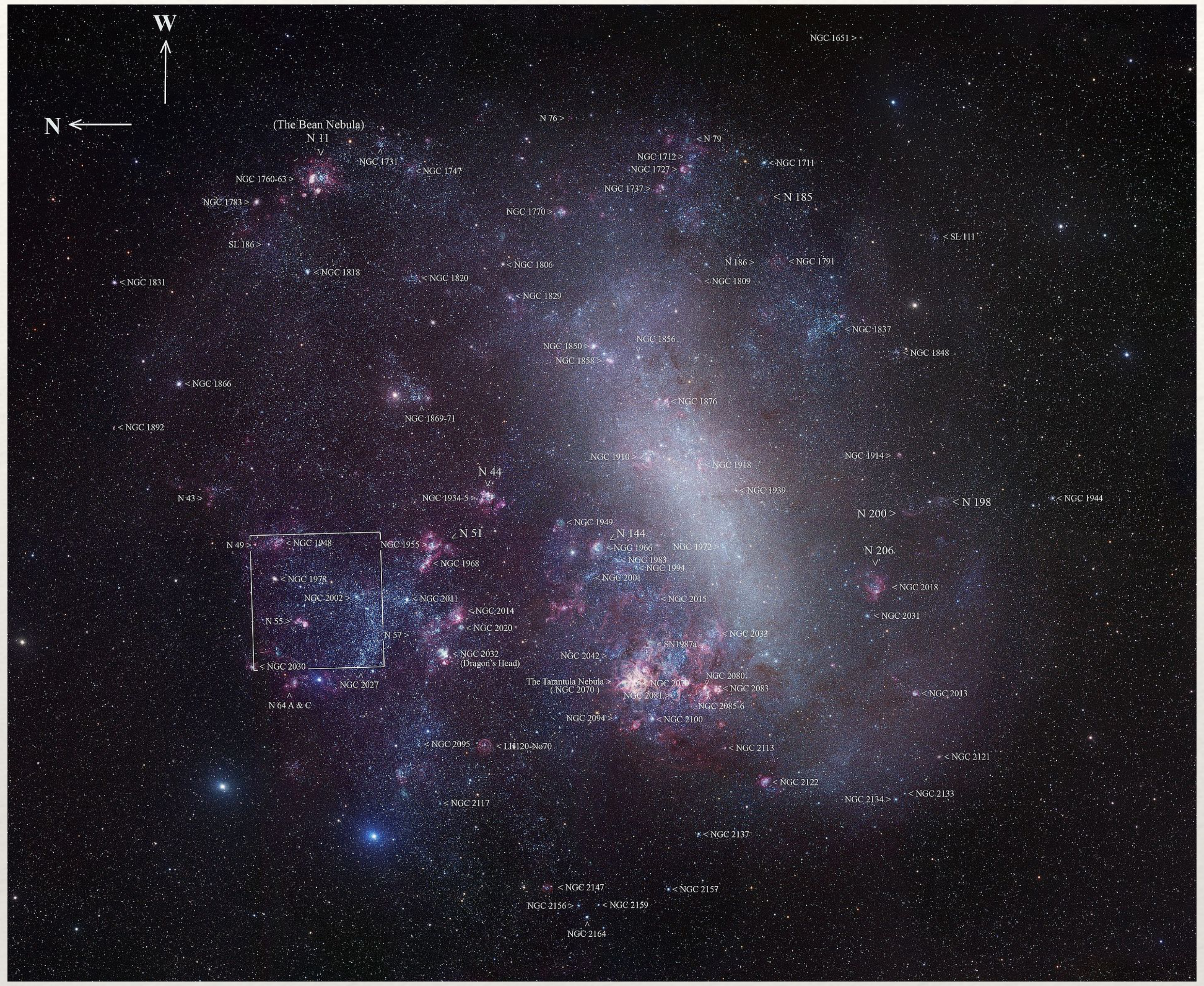
Good constraints??





WIMP-Large Magellanic Cloud (LMC)

WIMP-Large Magellanic Cloud



One of the closest satellites of the Galaxy!
~50 kpc

$M \sim 10^{11} M_\odot$

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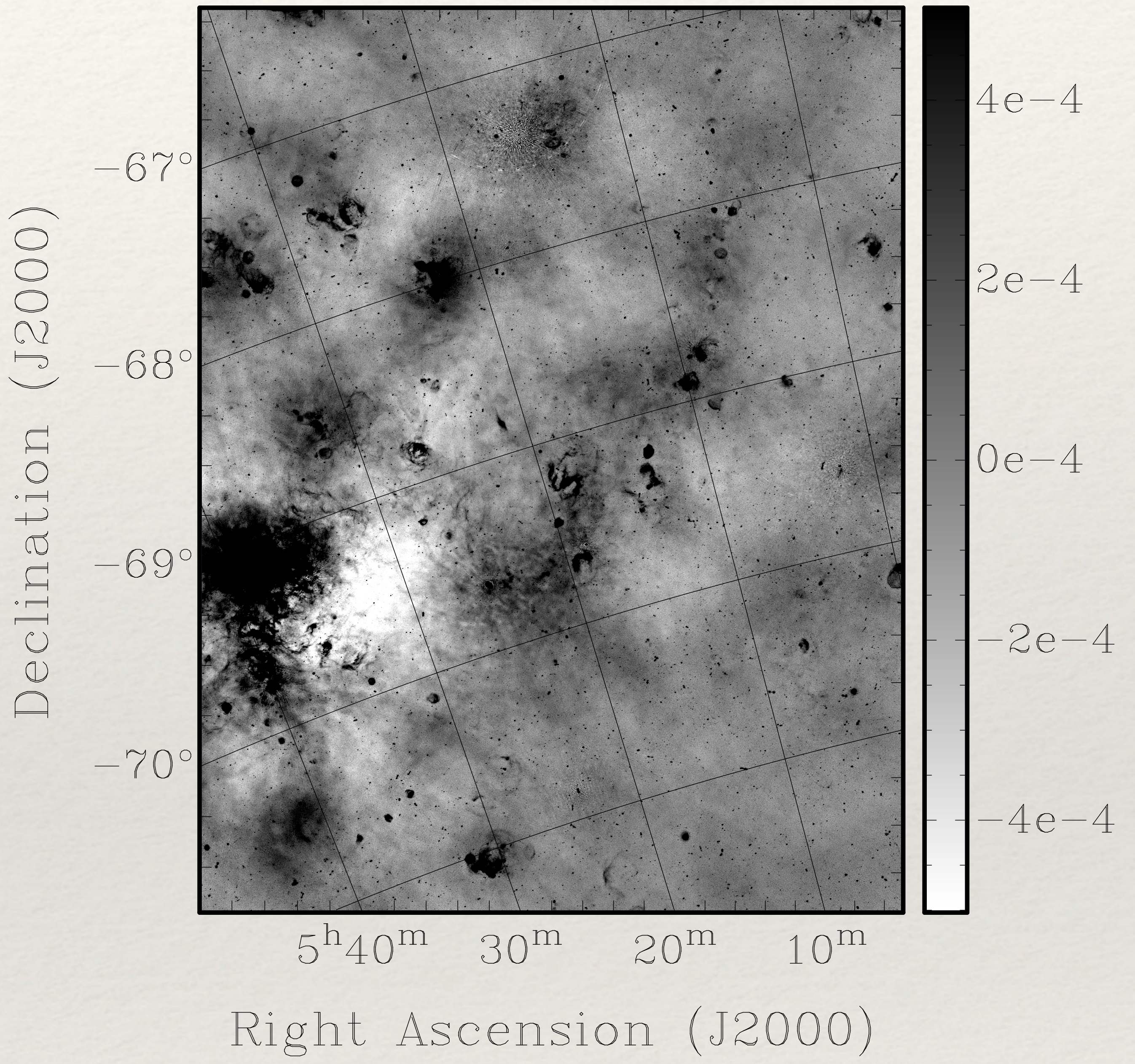
Australian Square Kilometer Array Pathfinder (ASKAP)
Evolutionary Map of the Universe (EMU)

Based on arXiv:2106.08025

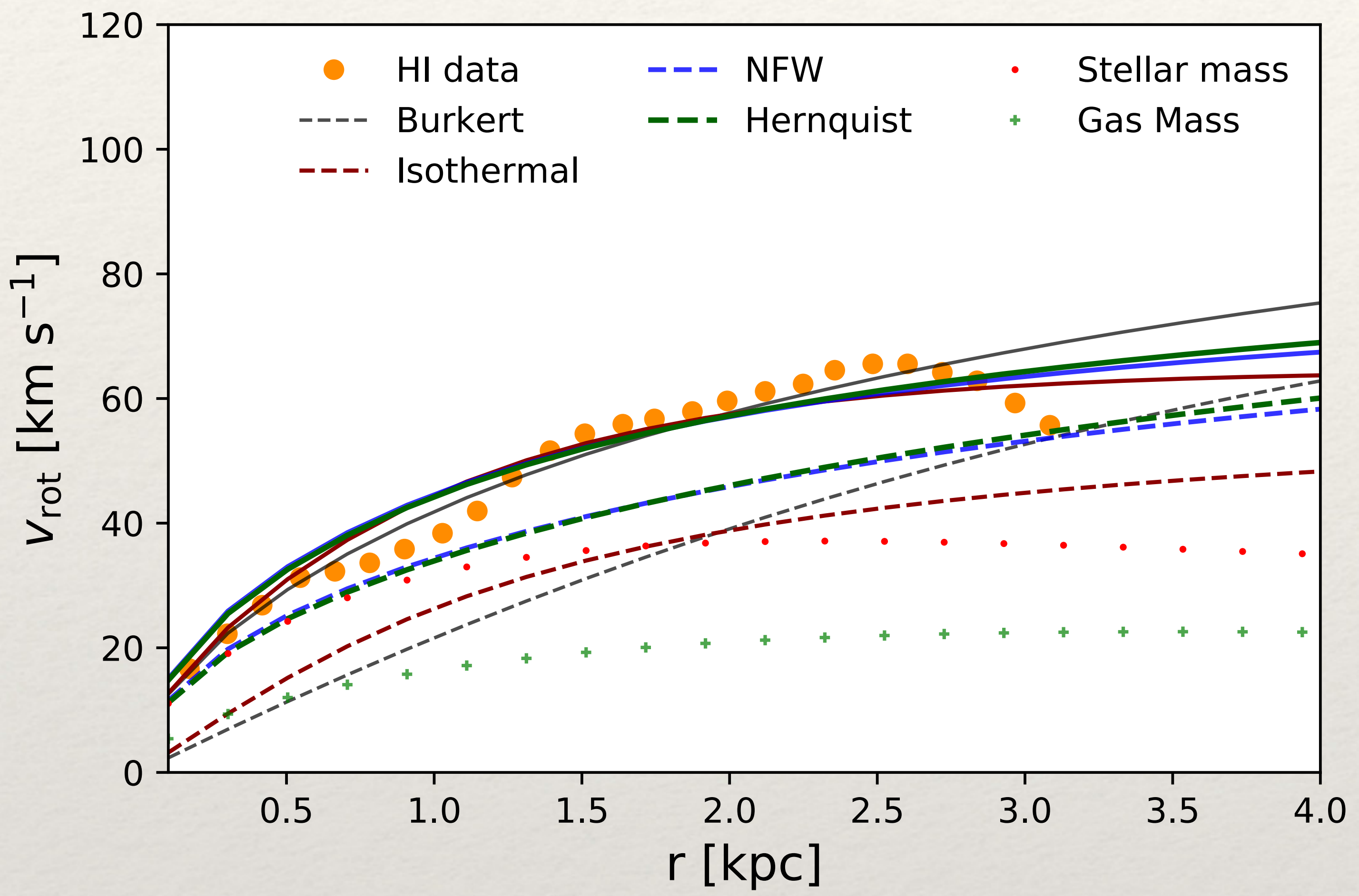


Observed map

CDM and SIDM

Results

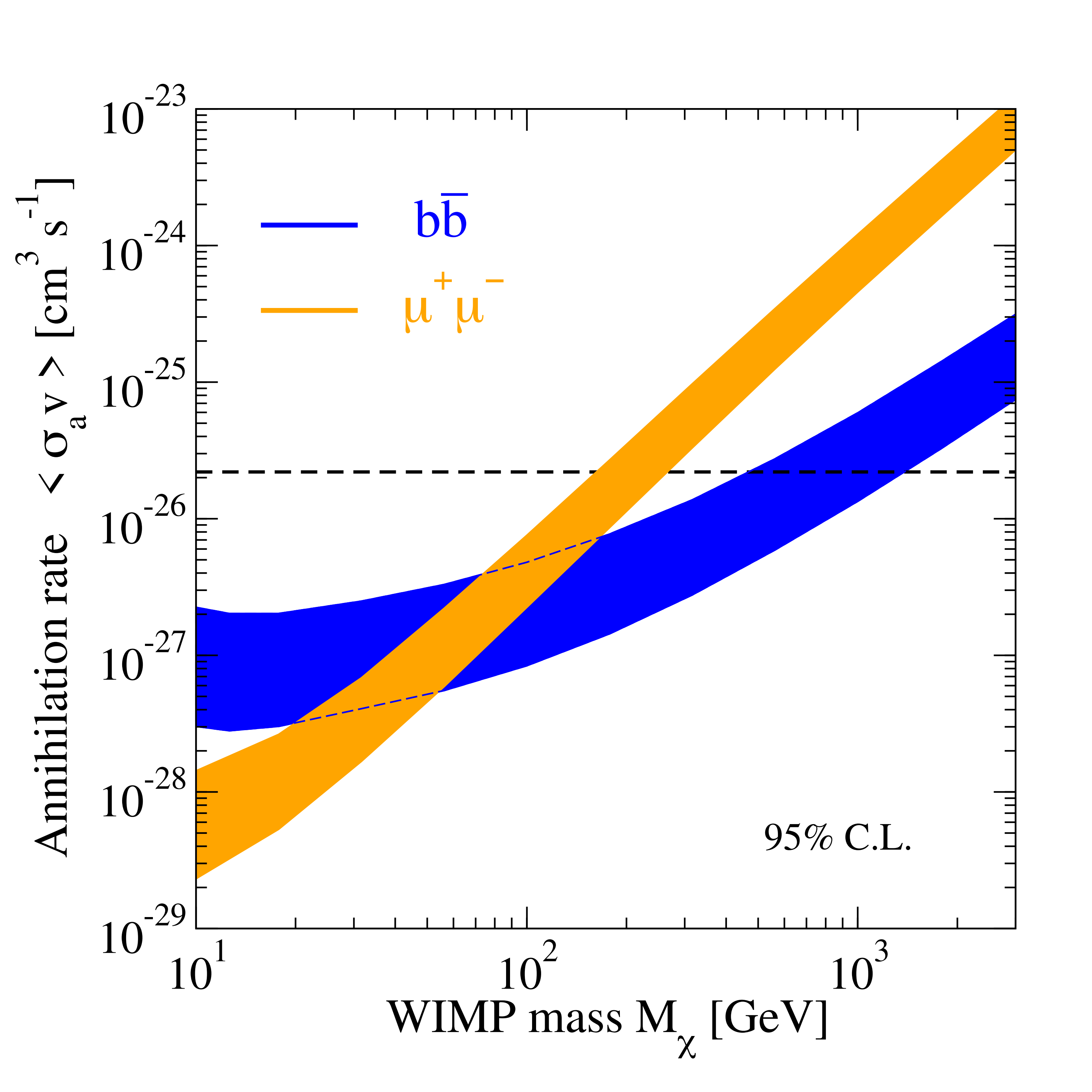
$$\chi\chi \to e^+e^-$$

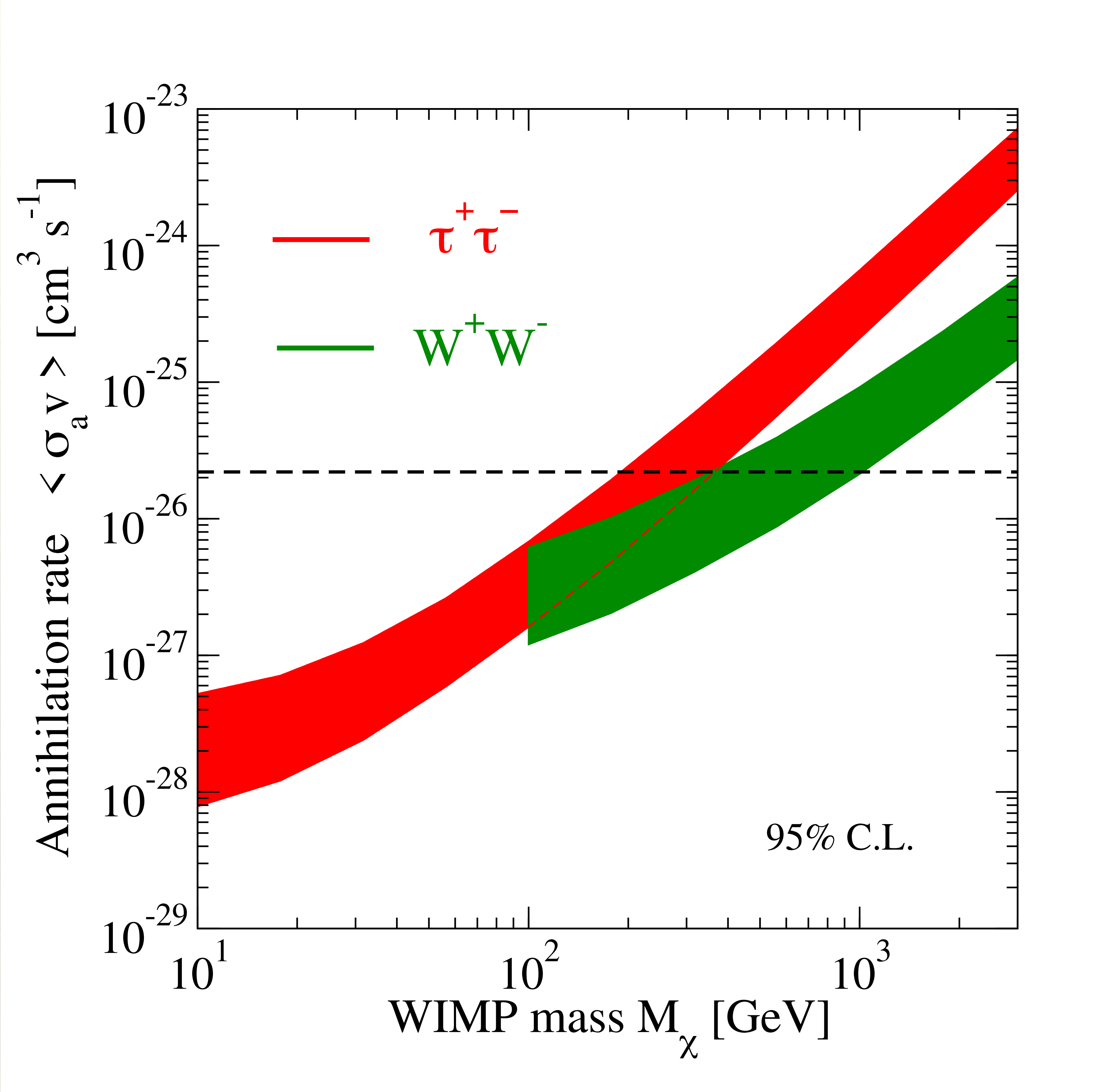


Dark Matter profile

$$J \sim 10^{20}\mathrm{GeV}^2\mathrm{cm}^{-5}$$

Total Magnetic Field ~4.3 μG
Gaensler et al. 2005





No preference for a diffuse emission from DM!

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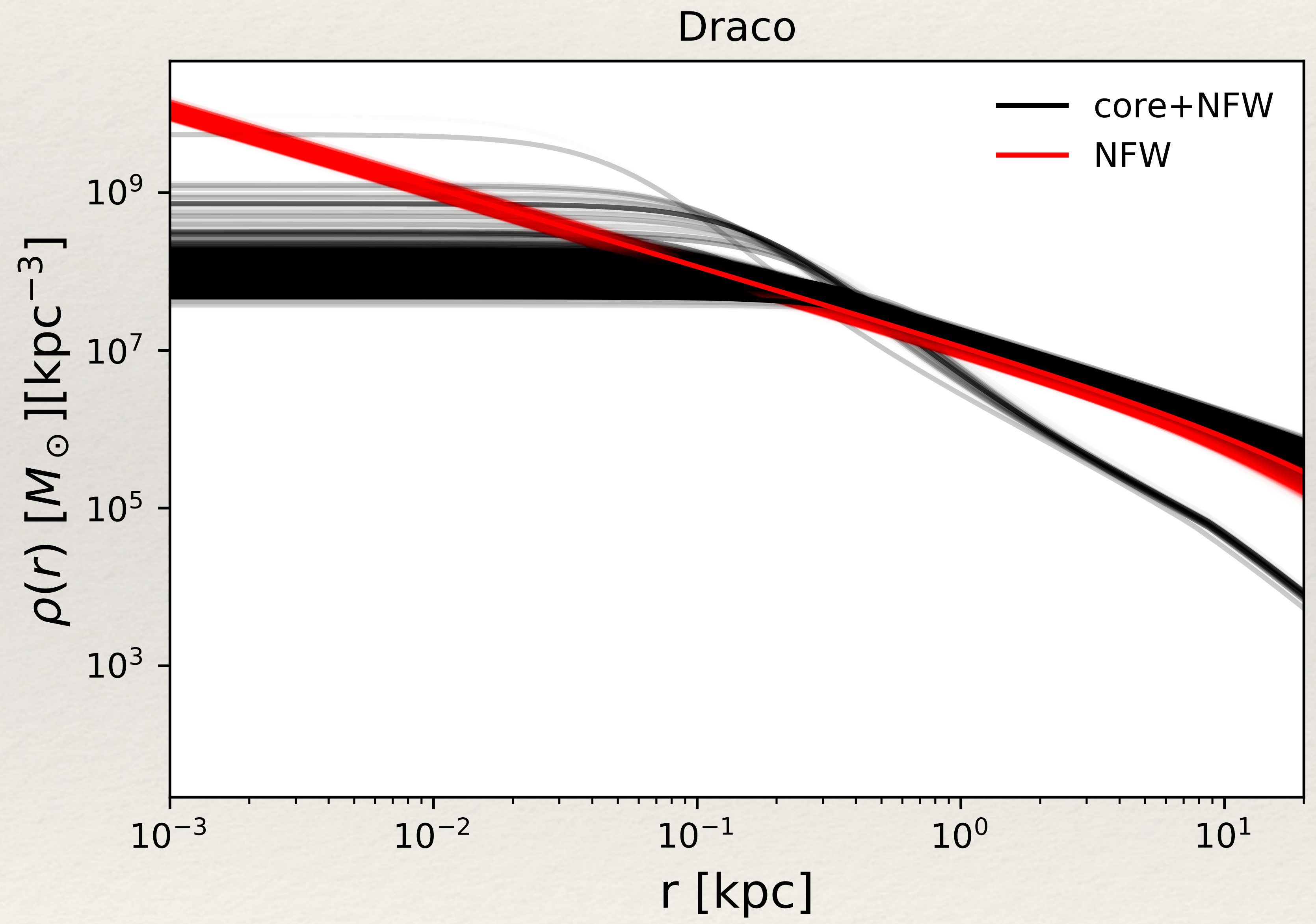
Based on arXiv:2106.08025

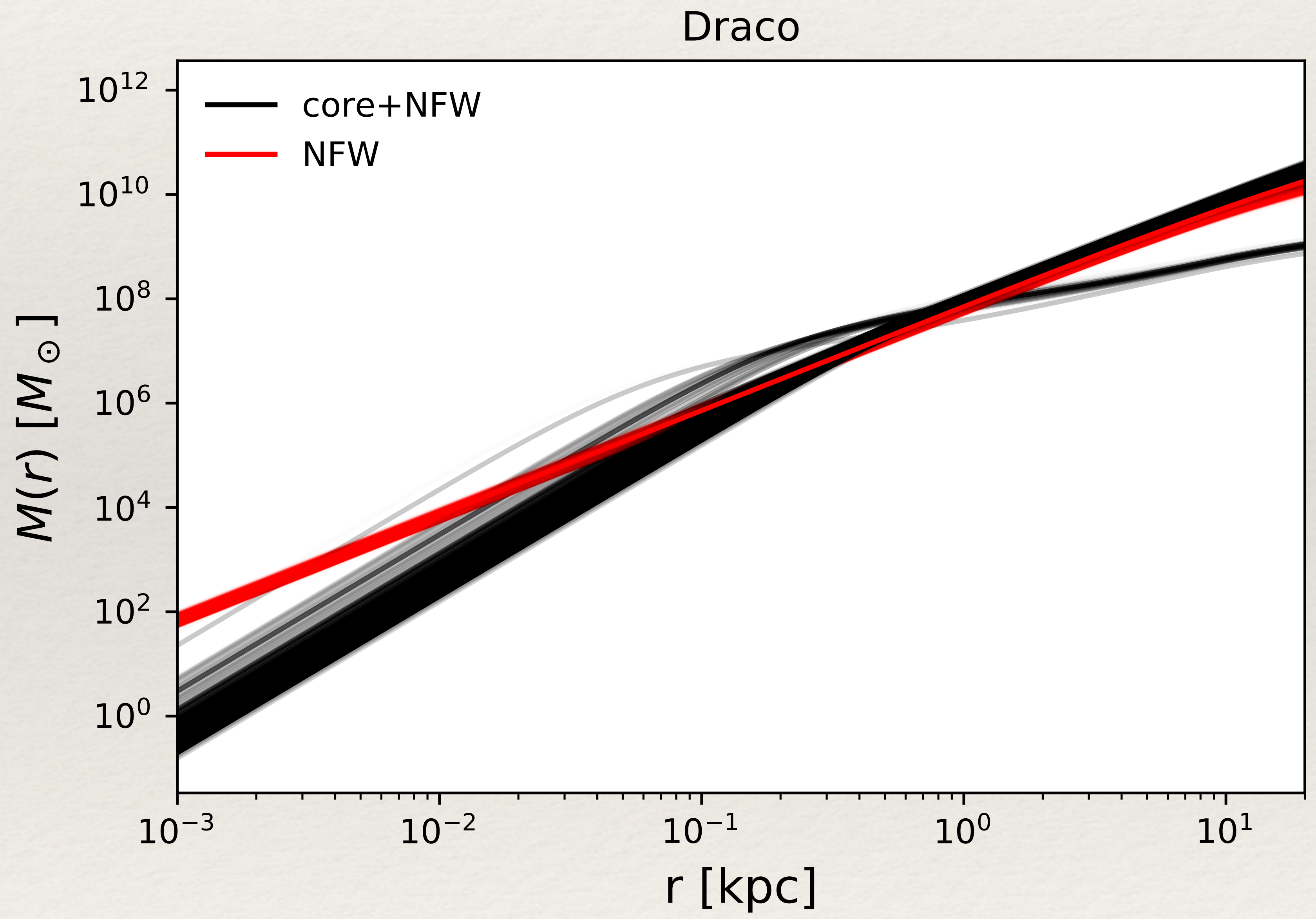
CDM and SIDM

Thanks!

Backup CDM vs CDM+SIDM

$$\sigma_r^2(r) = \frac{1}{\nu(r)g(r)} \int_r^{\infty} \frac{GM(r')\nu(r')}{r'^2} g(r`)dr'$$





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Backup/ Comparison