Study of Rotation Curves Diversity Problem in Dwarf Galaxies with SPARC and LITTLE THINGS in 3D Catalogs

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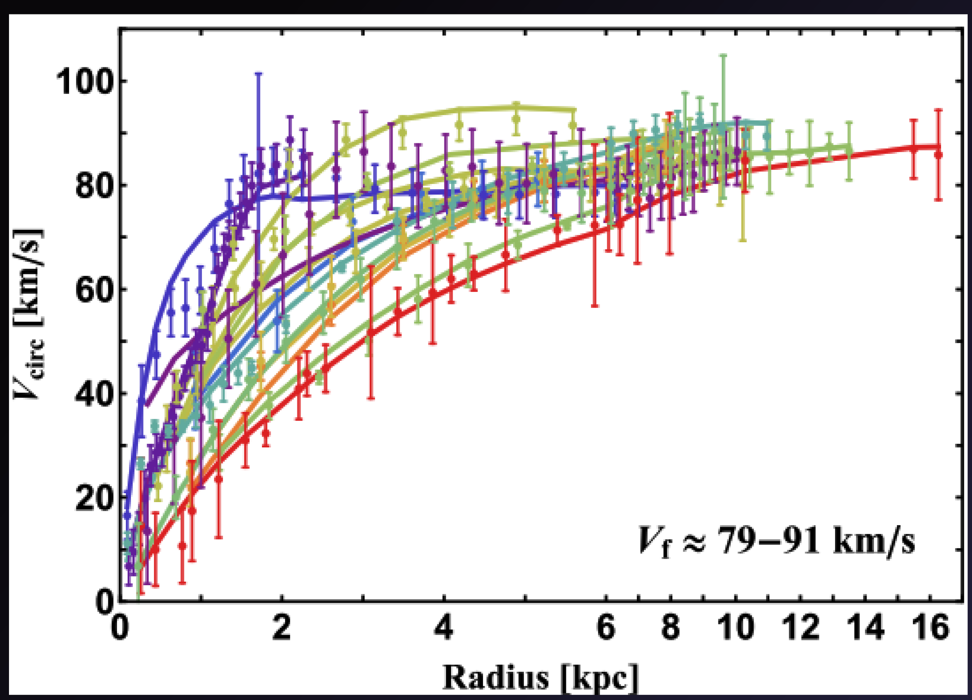
Background

Cosmological simulations of cold dark matter (CDM) predict self-similarity in galaxy formation, resulting in a cusped profile well described by the Navarro-Frenk-White (NFW) halo density profile. However, observations reveal diversity in the rotation curves of galaxies with similar total mass, characterized by flat velocity profiles (Ren et al., 2019).



Research Goals

We examine dwarf galaxies in the SPARC (Spitzer Photometry and Accurate Rotation Curves) and LITTLE THINGS in 3D (Local Irregulars That Trace Luminosity Extremes, The HI Nearby Galaxy Survey in 3D) catalogs to **explore possible explanations** for the diversities in the rotation curves, by incorporating **cold dark matter with baryonic feedback** (Di Cintio et al., 2014 model) and **self-interacting dark matter** (Spergel and Steinhardt, 2000).

Methods

Data Selection:

- Stellar Mass : $M_* < 10^{10} M_\odot$
- Inclination : $30^\circ < i < 75^\circ$
- Last datapoint : $r_{last} \geq 2r_{fid}$
- Total datapoint : $n \geq 10$
- Quality : $Q \neq 3$(SPARC) and do not include galaxies with distance rogues & equilibrium rogues (LT in 3D).

Total sample: **45 Galaxies**

Rotation curve shape parameter following Santos-santos et al. (2020).

$$\eta_{rot} = \frac{V_{fid}}{V_{max}}$$
$$r_{fid} = 2(V_{max}/70)kpc$$

Where V_{max} is the maximum rotational velocity in the rotation curves. Fiducial radius are considered as the transition of inner and outer region of the galaxy. One way to assess the strength of the baryon-induced core-cusp (BICC) mechanism is by examining **central baryon dominance.**

$$f_{bar} = \left(\frac{V_{bar}(r_{fid})}{V_{fid}}\right)^2$$

Rotation Curve Fitting

The MCMC method is employed to decompose the rotation curves into three components: a dark matter model, a disc, and a gas component. It is assumed that all dark matter models adhere to the concentration-mass relation. In the case of an NFW profile,

$$\log c_{200} = 0.830 - 0.098 \log(M_{200}/[10^{12} h^{-1} M_\odot])$$

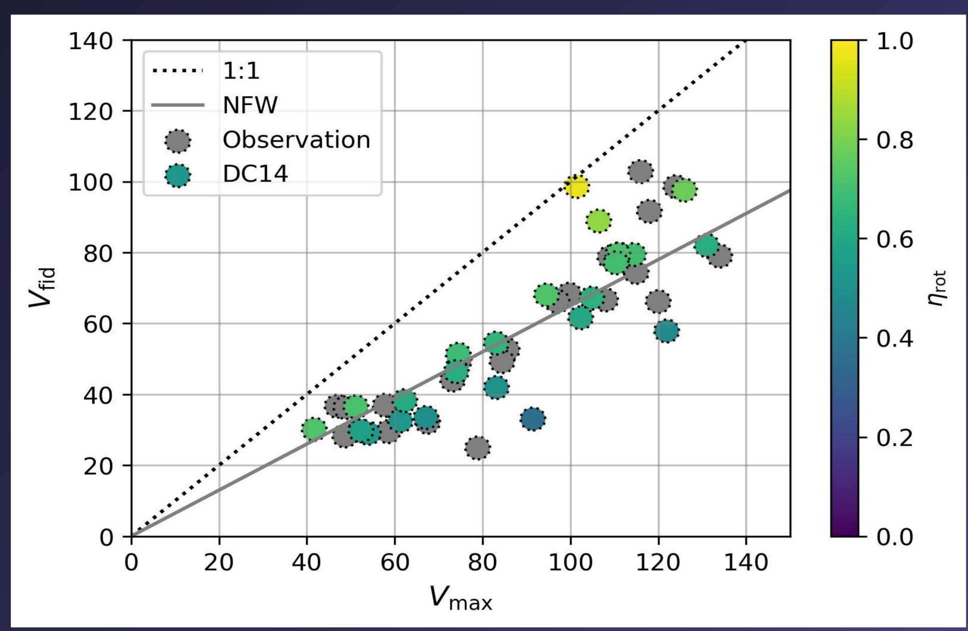
with estimated intrinsic scatter $0.11\ dex$.
The concentration for DC14 profile is related to that of NFW by (Di Cintio et al., 2014)

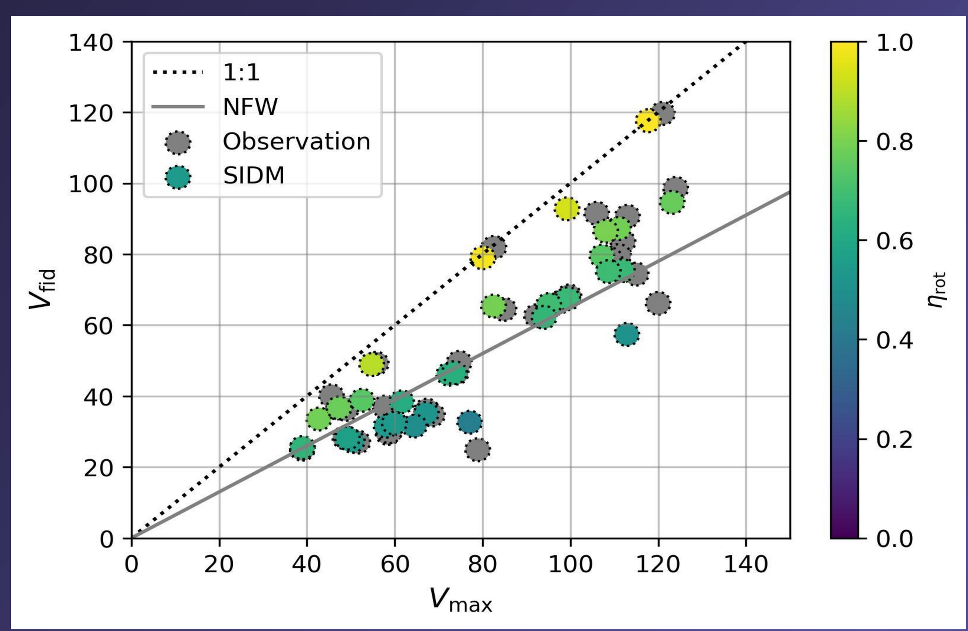
$$\log c_{200,DC14} = C_{200,NFW}\left(1.0 + e^{0.0001[3.4(X+4.5)]}\right)$$

Where $X = \log(M_{stellar}/M_{200})$

Model		Free parameter
NFW & DC14	V_{200}	Rotation velocity at the radius where the density is 200 times the critical density of the universe
	C_{200}	Concentration parameter (r_{200}/r_s)
SIDM	Γ_0	Scattering rate of DM particle
	σ_{v0}	One-dimensional dispersion velocity
All Models	M/L	Mass-to-light ratio

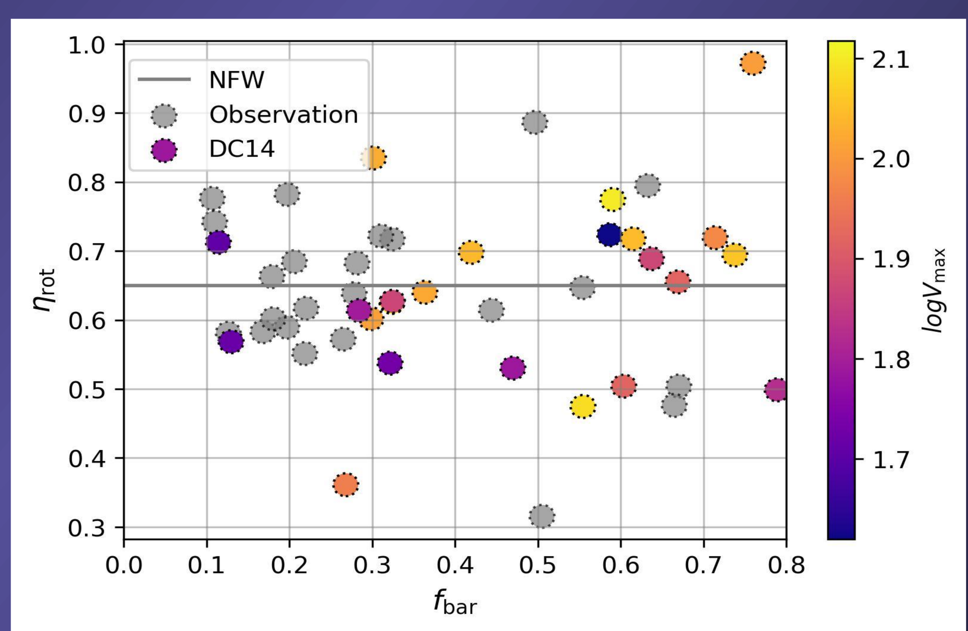
Rotation Curve Shape

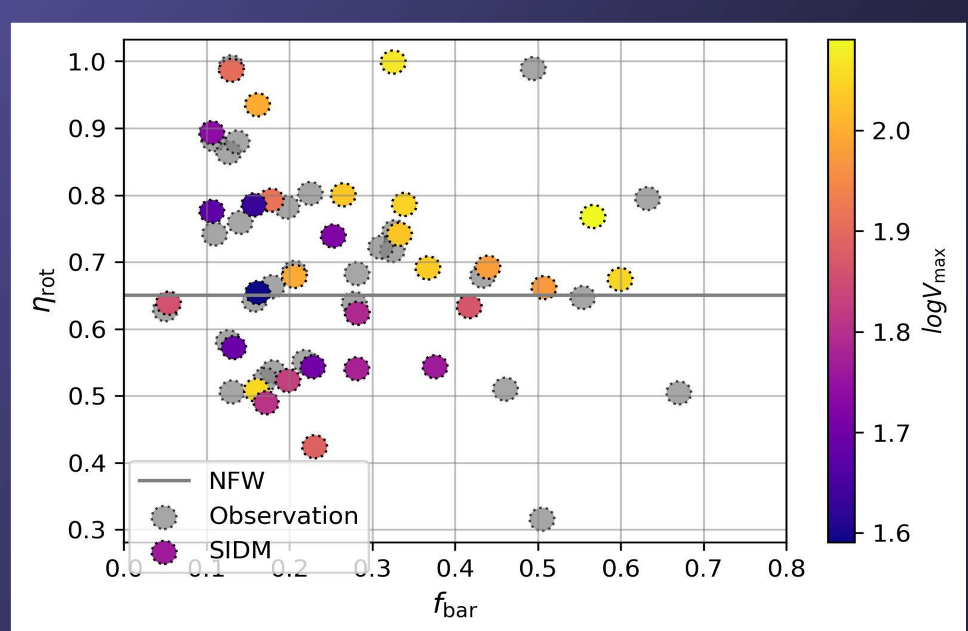




Both CDM with baryonic feedback and dark matter self-interaction could explain the diversity in rotation curve shapes by producing similar η_{rot} distributions.

Baryon Central Dominance





Rotation curve diversity is caused by the variation in baryon central dominance. Fitting results with the DC14 profile yield a higher mass-to-light ratio, which may be due to stellar-halo degeneracy in the fitting process.

Model Comparison

For each galaxy, the best model is chosen based on the lowest BIC value.

$$BIC = \chi_v^2 + p \log n$$

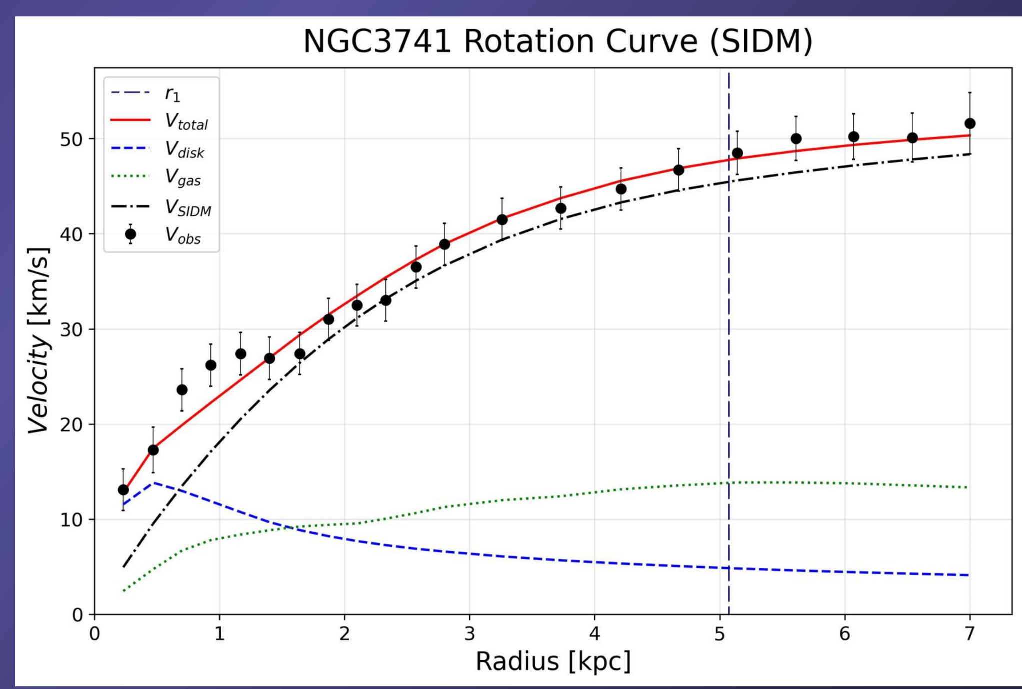
Where χ_v is the reduced chi-square, p is the total free parameter, n is the number of datapoints. Using Raftery Criterion, the best model has positive evidence to reject alternative model if $2 < \Delta BIC < 6$ and has strong evidence if $\Delta BIC > 6$.

	NFW	DC14	SIDM
Best Model	0	16	29

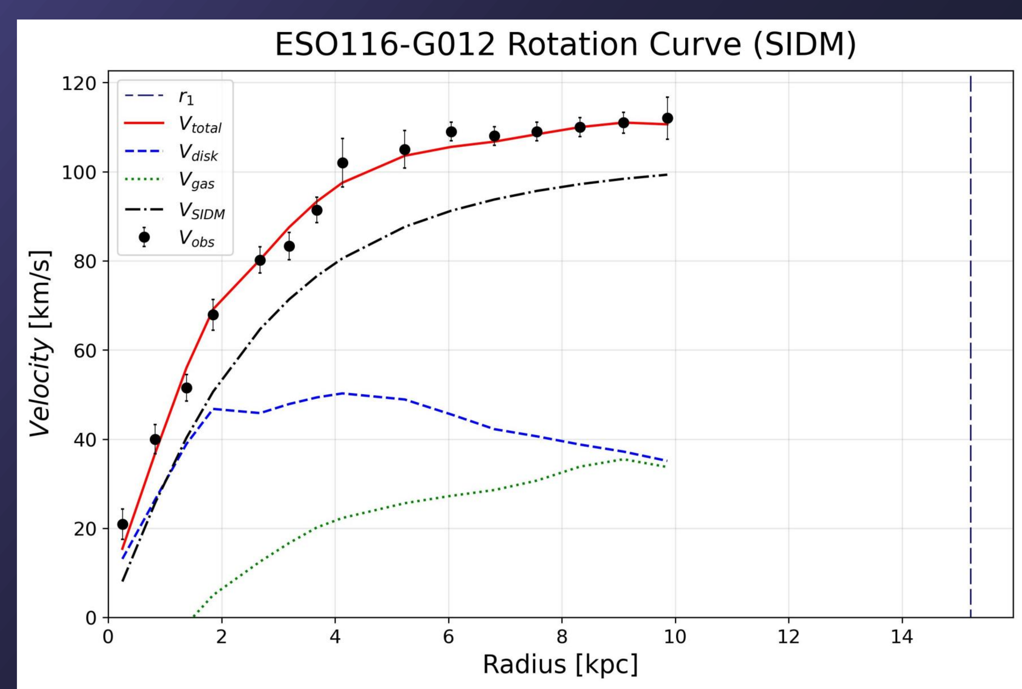
Number of Evidence to Reject the Model	NFW	DC14	SIDM
Positive Evidence	11	4	2
Strong Evidence	34	6	4

By Comparing the BIC values, it shows that the SIDM model has fewer rejections than the DC14 model.

SIDM Fitting Results



The SIDM model features a transition radius (r_1) where the inner isothermal profile meets the outer NFW profile.



Five out of six SIDM best-fit galaxies, which show strong evidence against the DC14 profile, have a transition radius (r_1) beyond their observed rotation curve, suggesting that their dark matter profiles may be well-modeled by an isothermal profile alone.

Reference

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- Navarro, J. F., Frenk, C. S., & White, S. D. M. 1997, ApJ, 490, 493
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- Spergel, D. N., & Steinhardt, P. J. 2000, PhRvL, 84, 3760