Self-interacting Dark Matter:
An Explanation for Diversity & Uniformity in Galactic Rotation Curves?

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Galactic rotation curves are “surprisingly diverse”...

Galaxies with similar $V_{\text{flat}}$ (proxy for mass) can have very different inner rotation curves.
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Galactic rotation curves are “surprisingly diverse”...

$V_{\text{flat}} \sim 240-315 \text{ km/s}$
Galaxies with similar $V_{flat}$ (proxy for mass) can have very different inner rotation curves.
...but also very uniform in other aspects.

“Radial acceleration relation” (McGaugh+16)

Tight relation between $g_{\text{baryons}}$ and $g_{\text{obs}}$, despite the wide range mass distributions in galaxies

Signature of MOND? Or, dark matter that can respond to the influence of baryons?

Need to assume stellar M/L ratio
SIDM interactions
+ scatter in concentration-mass relation
+ variety in baryon distributions
= observed diversity in rotation curves?

If so, do other quantities/relations (stellar mass-to-light ratios, cosmological concentration-mass relation) also agree with accepted ranges?

Do we recover the radial acceleration relation?
How is the density profile in an SIDM halo determined?
characteristic scale $r_1$

\[ \text{rate} \times \text{time} \approx \frac{\langle \sigma v \rangle}{m} \rho(r_1) t_{\text{age}} \approx 1 \]
Isothermal SIDM core specified by density $\rho$ and 1D dispersion $\sigma_0$

$$\sigma_0^2 \nabla^2 \ln \rho = -4\pi G(\rho + \rho_b)$$

baryon densities affect SIDM profile
Collisionless NFW profile

\[ \frac{\rho_s}{(r/r_s)} (1+r/r_s)^{-3} \]
Same mass range of galaxies can have very different SIDM density profiles (and rotation curves) due to:

- Scatter in concentration-mass relation ($r_s$) leads to scatter in core radius $r_1$
- Variety of baryon content and distribution leads also increases diversity in inner SIDM distribution
Two methods of finding best-fit SIDM profiles from rotation curves and surface brightness profiles (SPARC sample, Lelli+16):

1. Fit using template grid of baryonic disk potentials and NFW halos

2. MCMC fit
MCMC fit

Want to find:

• SIDM density profile and contribution to rotation curve

• Stellar mass-to-light ratio

Specify:

• Fixed* self-interaction cross section $\sigma/m$
  
  * assumes that any variation in scattering cross section within a velocity-dependent SIDM model is small within mass ranges considered

• Cosmological $v_{\text{max}} - r_{\text{max}}$ (a.k.a. concentration-mass) relation from N-body simulations
Red = dark matter
Blue = total baryons
Green = disk
Grey = total model

$V_{\text{flat}} \sim 300 \text{ km/s}$

$V_{\text{flat}} \sim 180 \text{ km/s}$
Red = dark matter
Blue = total baryons
Green = disk
Grey = total model

\[ V_{\text{flat}} \approx 55 \text{ km/s} \]

\[ V_{\text{flat}} \approx 80 \text{ km/s} \]
Fits prefer SIDM cross sections $\sim 3 \text{ cm}^2/\text{g}$ over lower cross sections or collisionless DM
Strong baryonic feedback vs. SIDM under the influence of baryons

Grey lines = simulations

Santos-Santos + 17, NIHAI0 collaboration

This work
Stellar mass to light (M/L) ratios from MCMC fits
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General agreement with population synthesis models
(M/L ~0.4-0.6)
Stellar mass to light (M/L) ratios from MCMC fits

Radial variation in stellar populations driving M/L higher? Beware of bias from inner data points
Use M/L values to predict $g_{\text{baryon}}$ and recover radial acceleration relation

McGaugh + 16

This work
Scatter in data points from empirical radial acceleration relation is equal to / less than McGaugh+16

\[
g_{\text{obs}} = \mathcal{F}(g_{\text{bar}}) = \frac{g_{\text{bar}}}{1 - e^{-\sqrt{g_{\text{bar}}/g \uparrow}}} \]

**McGaugh+16**
(M/L fixed to 0.5)

**This work**
(M/L ratios freely fit to data with SIDM)
Takeaway message

Self-interacting dark matter with interaction cross sections \(~\text{few cm}^2/\text{g}\) can fit a *diversity* of rotation curve shapes across a variety of galaxy masses...

… while also recovering the *uniformity* in the radial acceleration relation between $g_{\text{baryon}}$ and $g_{\text{obs}}$. 