

Self-Interacting Dark Matter and Its Signatures

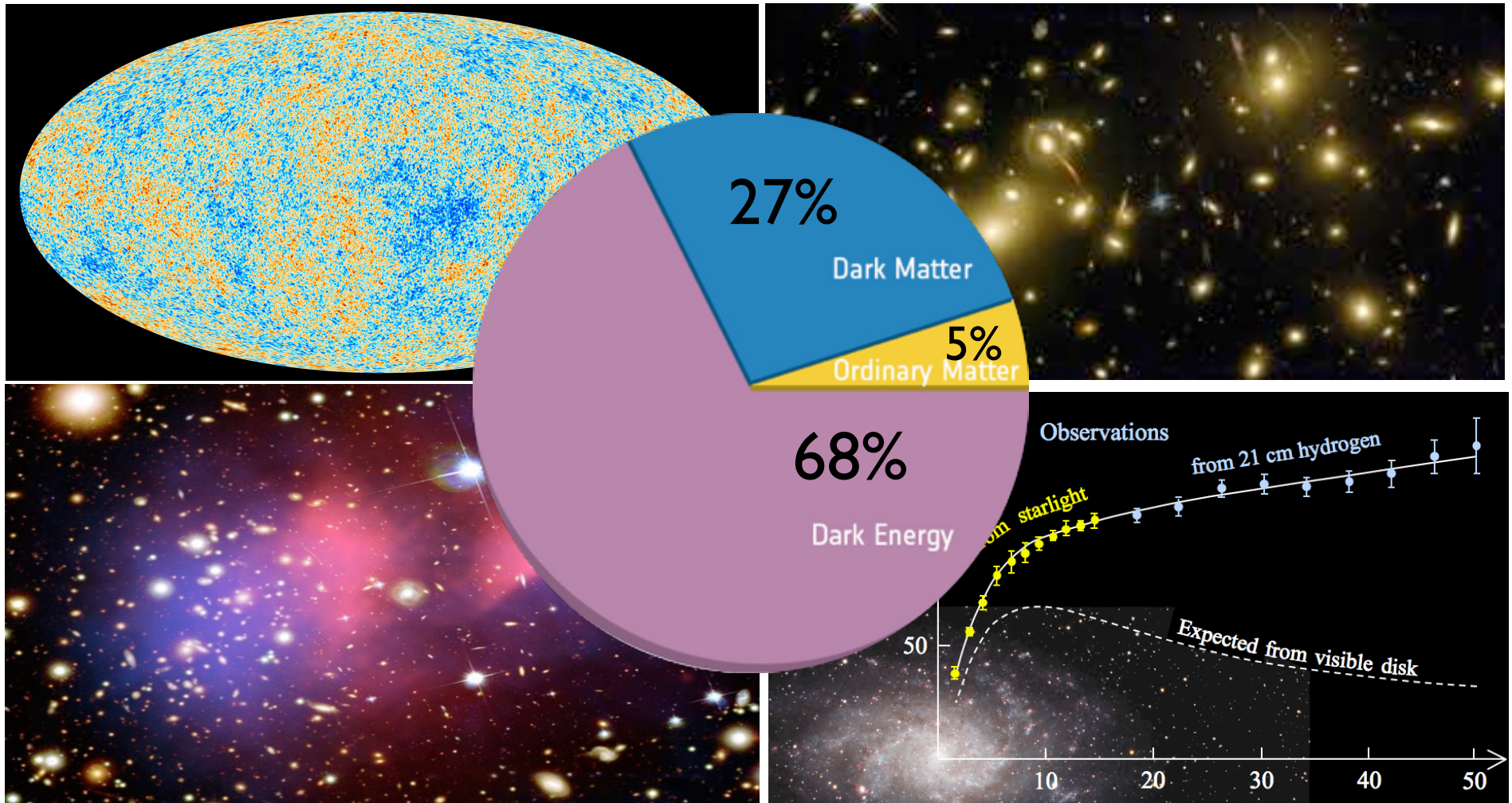
Hai-Bo Yu

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Rabi-Fest, University of Maryland, October 21, 2022

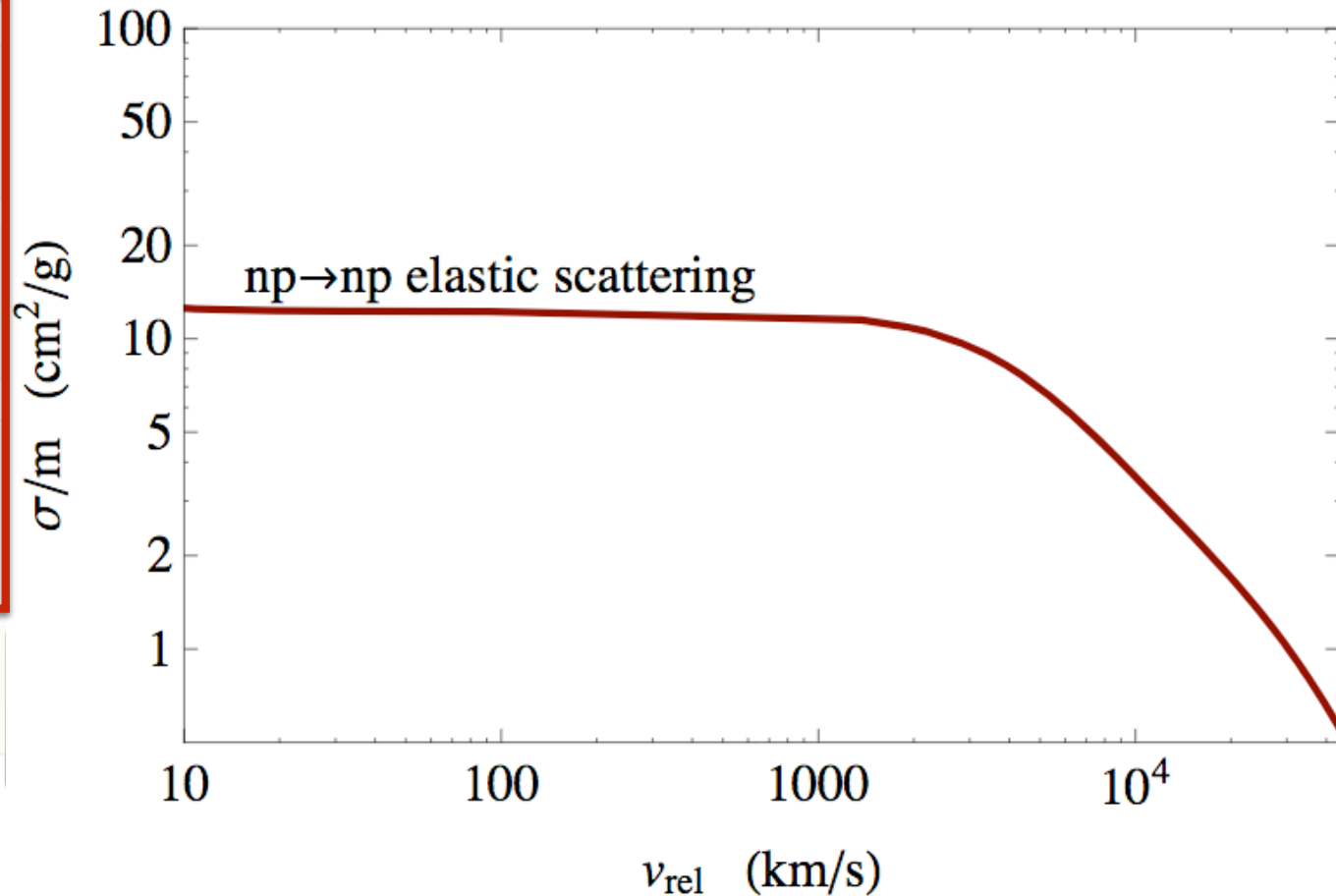
Dark Matter



- The prevailing dark matter paradigm: **cold, collisionless particles**
- CDM works very well on large scales $>O(100)$ kpc
- Testing CDM on galactic and sub-galactic scales

Beyond the CDM Paradigm

mass →	≈2.3 MeV/c ²	≈1.275 GeV/c ²	≈173.07 GeV/c ²
charge →	2/3	2/3	2/3
spin →	1/2	1/2	1/2
	u up	c charm	t top
	≈4.8 MeV/c ²	≈95 MeV/c ²	≈4.18 GeV/c ²
	-1/3	-1/3	-1/3
	1/2	1/2	1/2
QUARKS	d down	s strange	b bottom
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²
	-1	-1	-1
	1/2	1/2	1/2
	e electron	μ muon	τ tau
LEPTONS	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²
	0	0	0
	1/2	1/2	1/2
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino

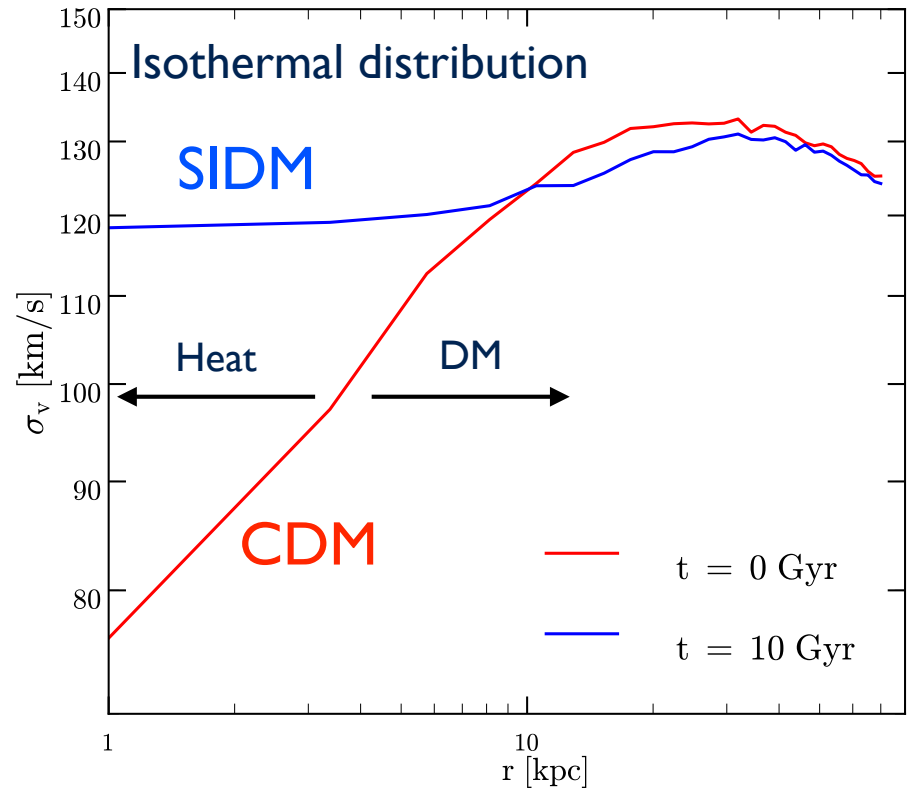
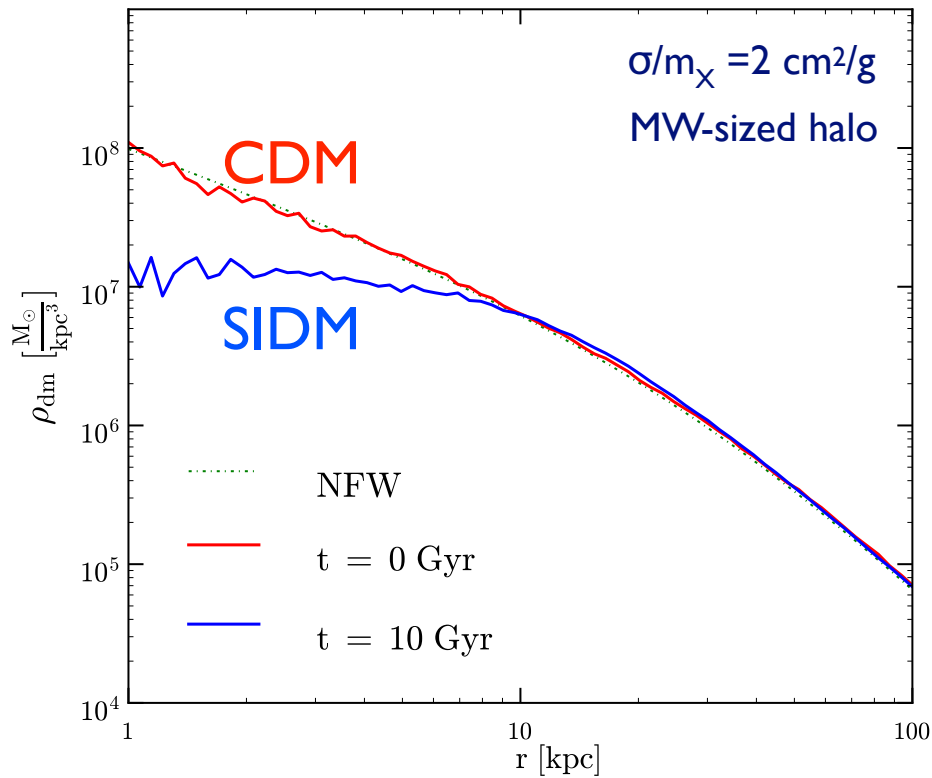


Tulin, HBY (2017); data from Obloinsk+(2011)

- Most of matter particles in the Standard Model have large self-interactions
- What happens if dark matter particles have large/strong self-interactions

Self-Interacting Dark Matter

- Self-interactions thermalize the inner halo



$\sigma/m_X > 1 \text{ cm}^2/\text{g}$ (close to nuclear scales)

$$\Gamma \simeq n\sigma v = (\rho/m_X)\sigma v \sim H_0$$

Spergel, Steinhardt (PRL 1999)

see Tulin, HBY (2017) for a review

Searching for Strongly Interacting Massive Particles (SIMPs)

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(May, 1999)

Mirror Dark Matter and Galaxy Core densities

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(January, 2000)

Mirror Matter as Self Interacting Dark Matter

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(November, 2001)

Reactor searches for neutrino magnetic moment as a probe of extra dimensions

R. N. Mohapatra, Siew-Phang Ng, and Haibo Yu **My first paper with Rabi**

Department of Physics, University of Maryland, College Park, Maryland 20742, USA

(Received 6 May 2004; published 16 September 2004)

Journal of **C**osmology and **A**stroparticle **P**hysics
An IOP and SISSA journal

Hidden charged dark matter

My first paper on SIDM

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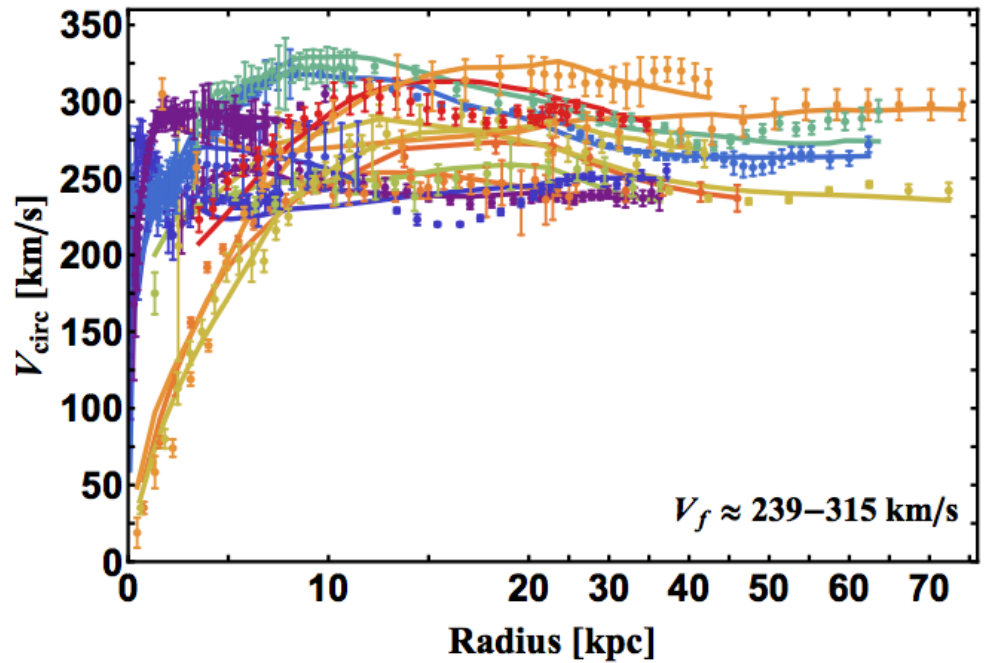
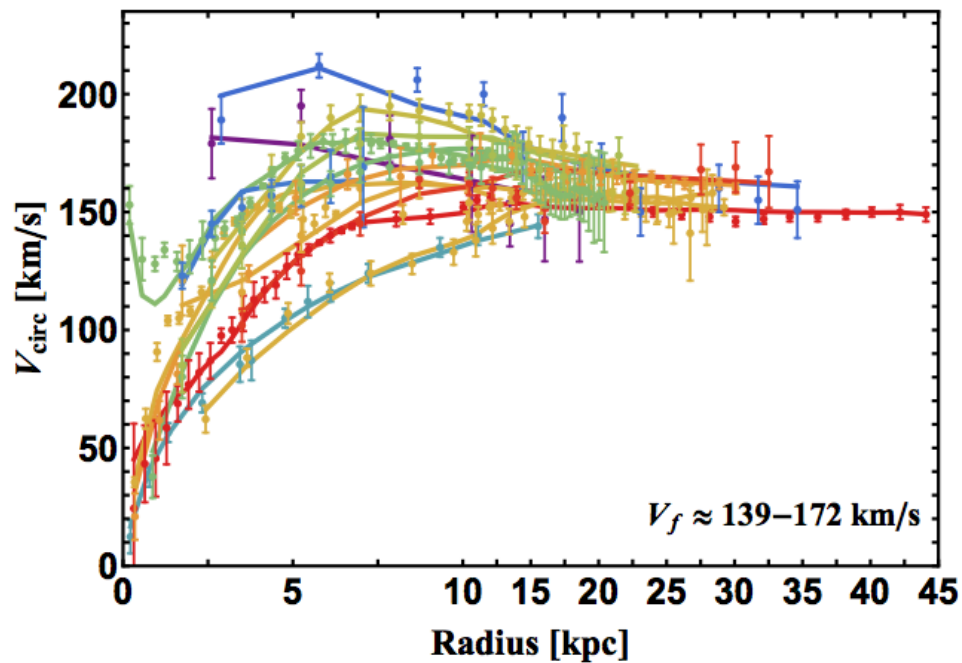
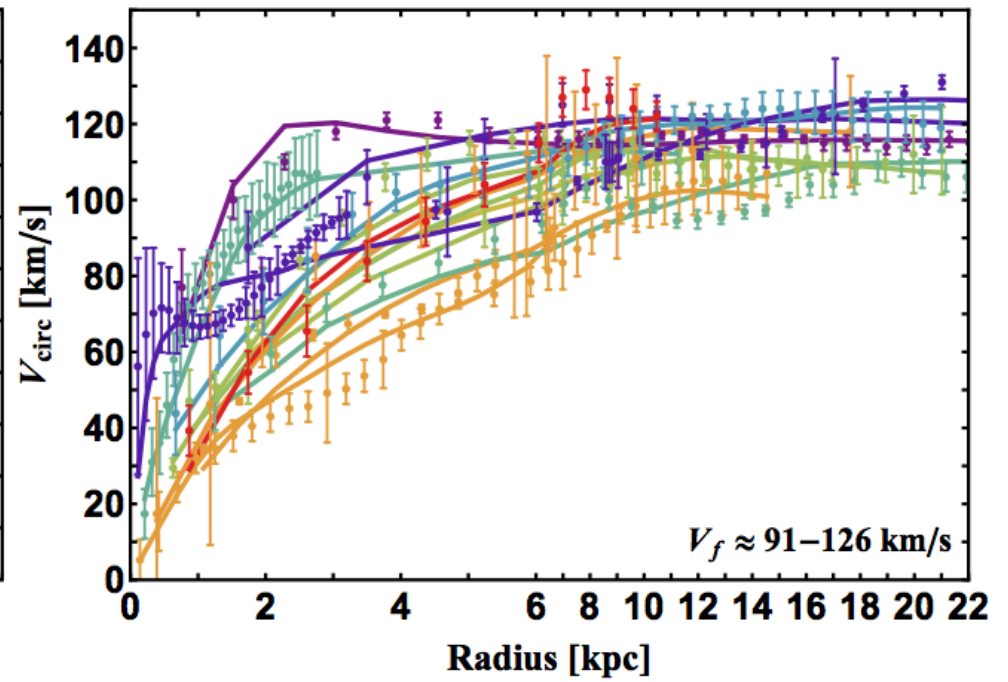
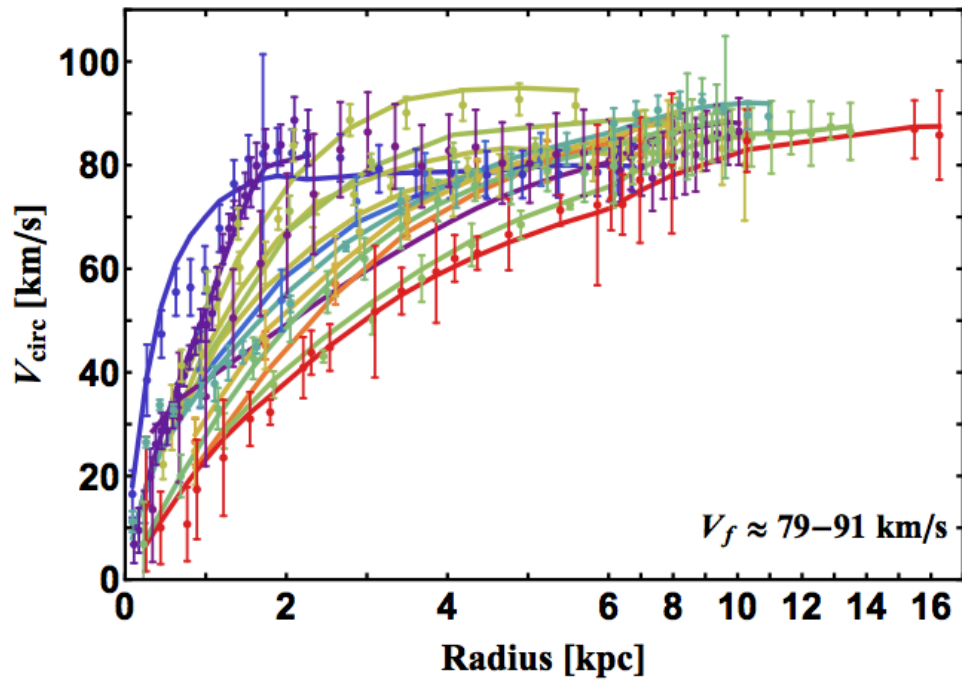
Halo-Shape and Relic-Density Exclusions of Sommerfeld-Enhanced Dark Matter Explanations of Cosmic Ray Excesses

SIDM with a Yukawa potential

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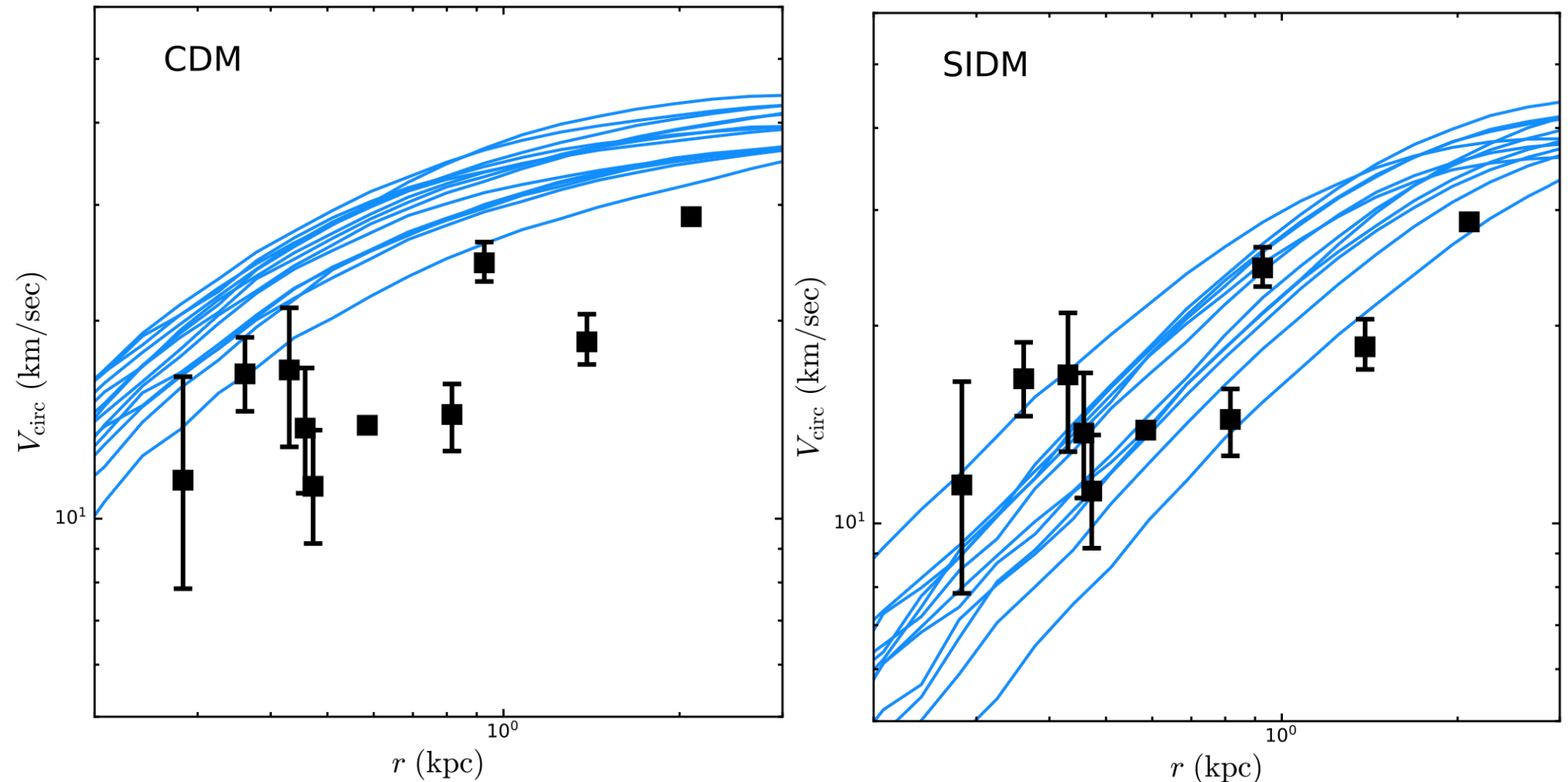
(Received 15 December 2009; published 15 April 2010)



Diversity of rotation curves of spiral galaxies; Challenge for CDM

w/Kaplinghat, Tulin (PRL 2016)
 w/Kamada, Kaplinghat, Pace (PRL 2017)
 w/Ren, Kwa, Kaplinghat (PRX 2018)
 w/Creasey+ (MNRAS 2018)

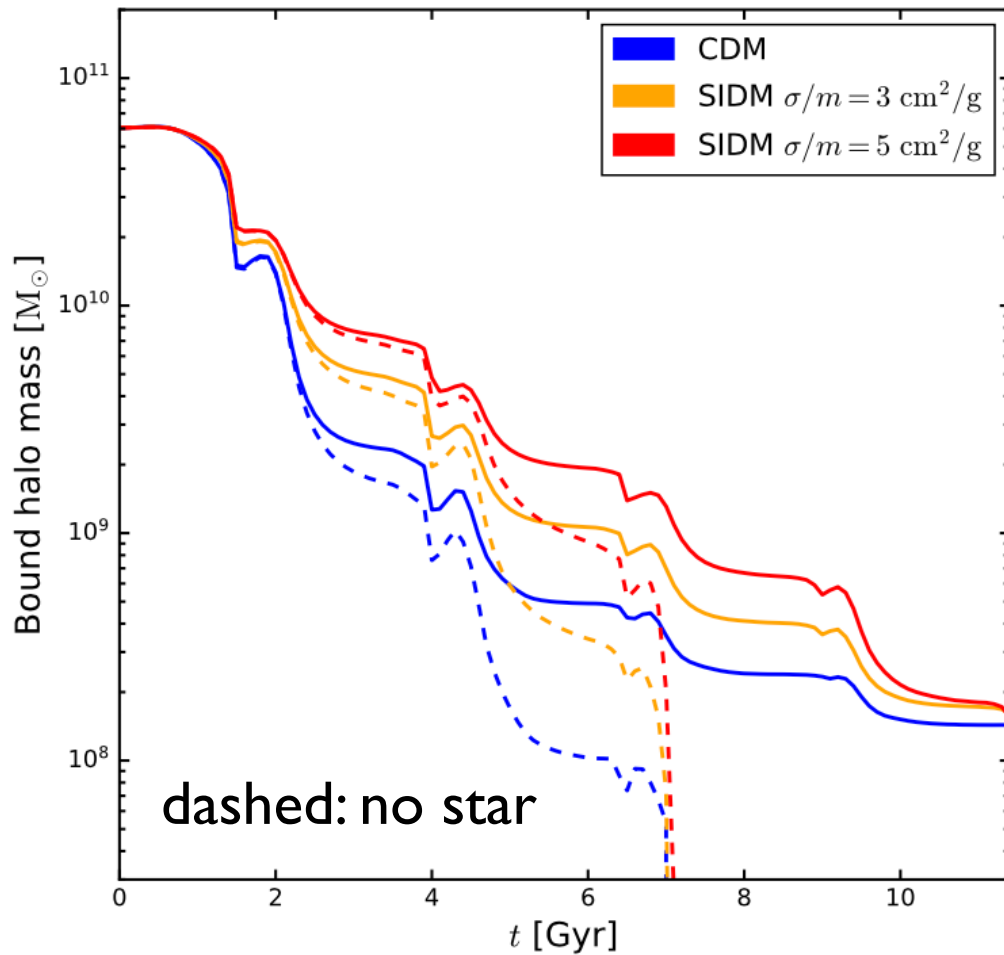
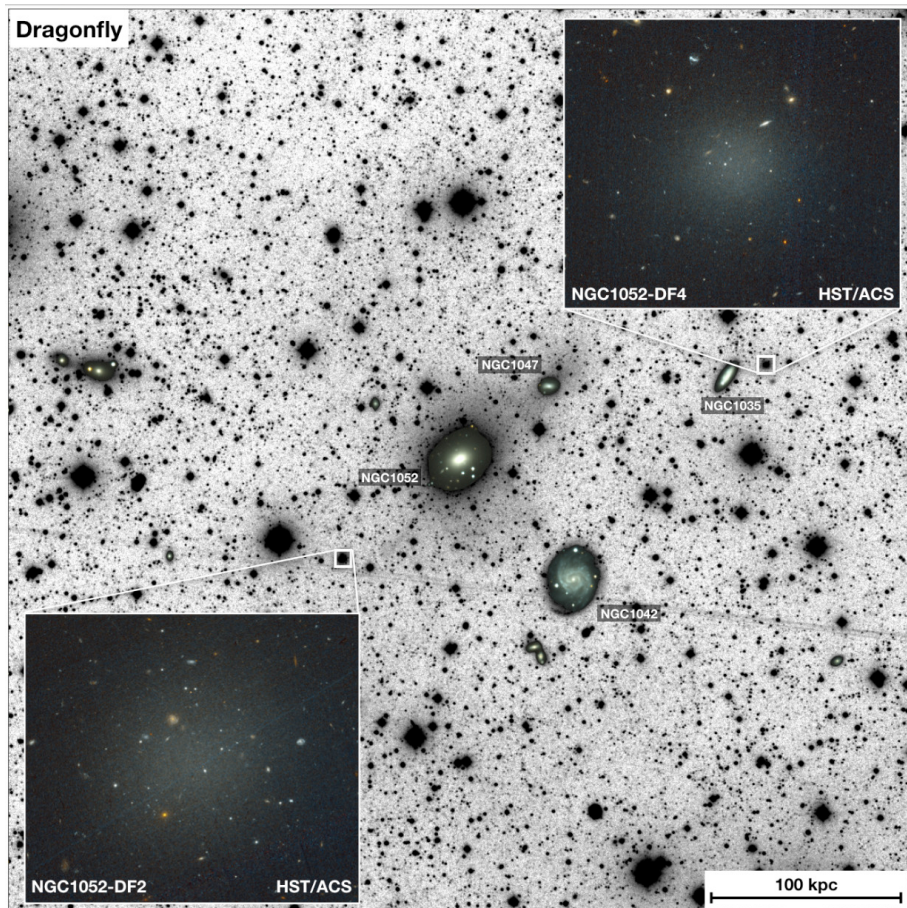
Dwarf Galaxies in the Local Group



- Blue curves denote the simulated halos that are supposed to host 10 observed dwarf galaxies (black squares) in the Local Group of the Milky Way
- CDM: the simulated halos are too dense

w/ Yang, Nadler (to appear)

Dark-Matter-Deficient Galaxies



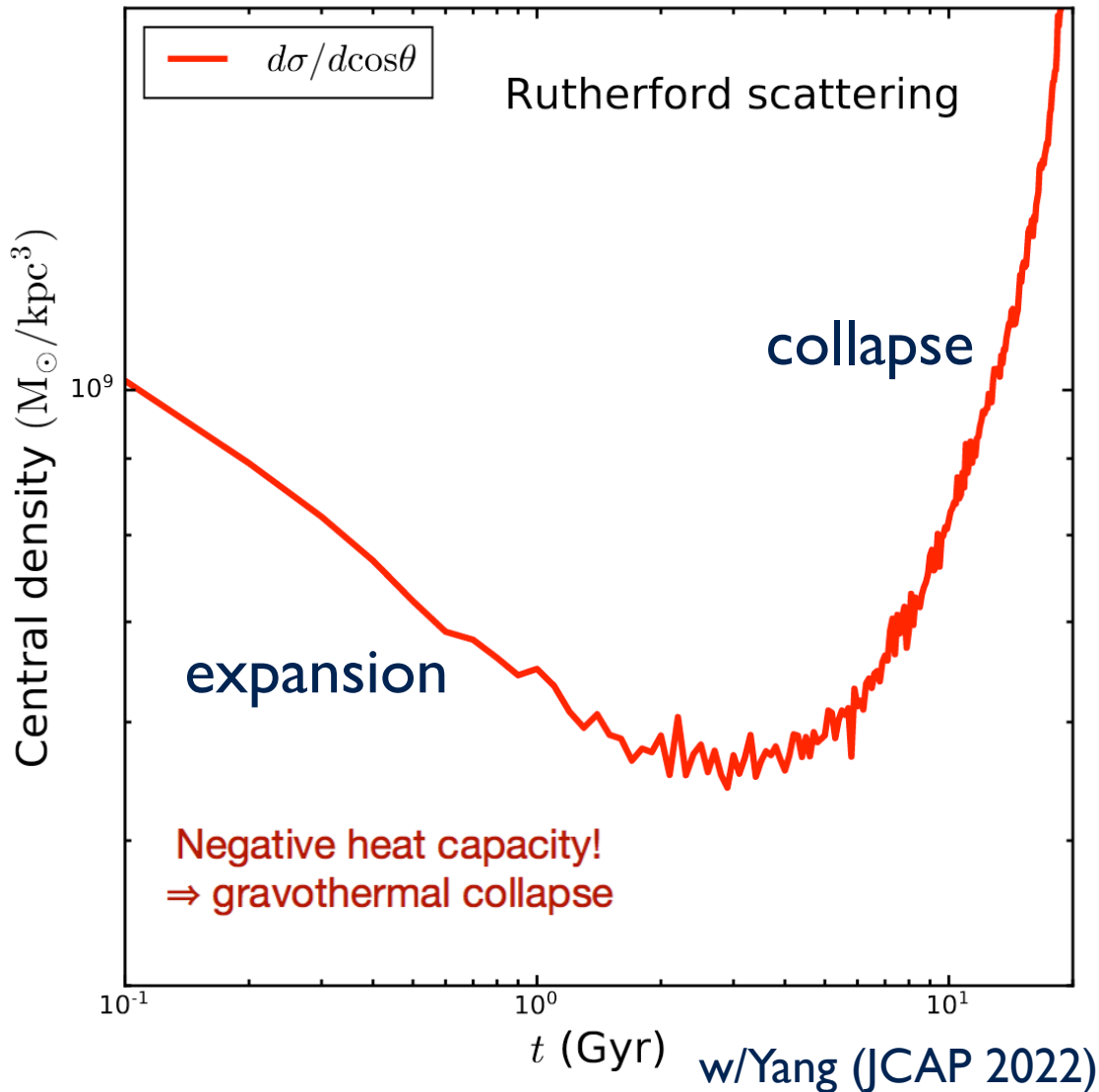
van Dokkum+ (Nature 2018, AJPL 2019)

- DF2/DF4 may belong to the NGC1052 group
- Tidal stripping can remove dark matter mass

Halo concentration c_{200}
 CDM: 4 (-4 σ from the median)
 SIDM3: 7 (-1.8 σ)
 SIDM5: 10 (-0.4 σ)

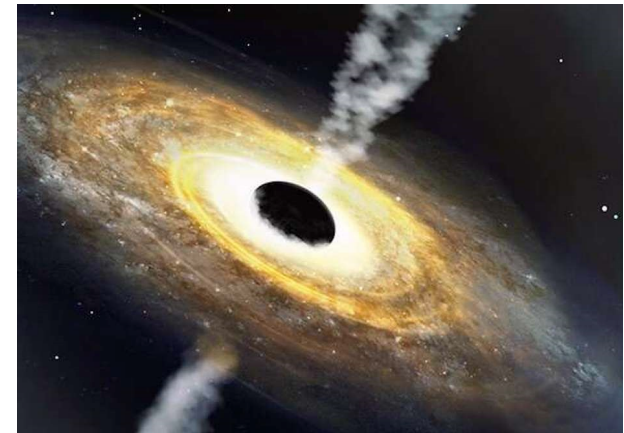
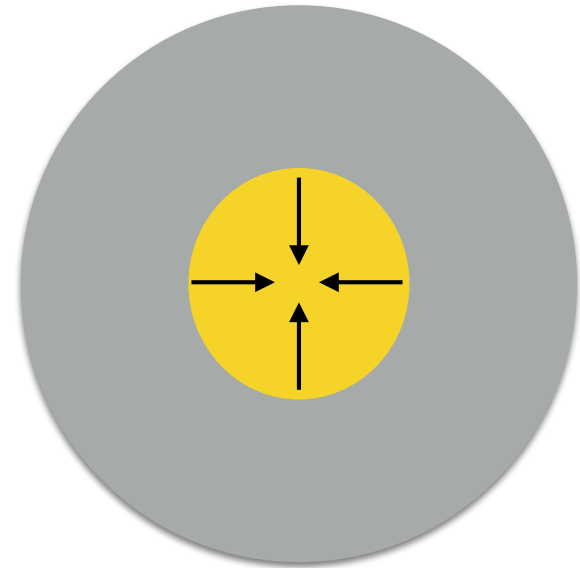
w/Yang, An (PRL 2021)

Seeding Supermassive Black Holes



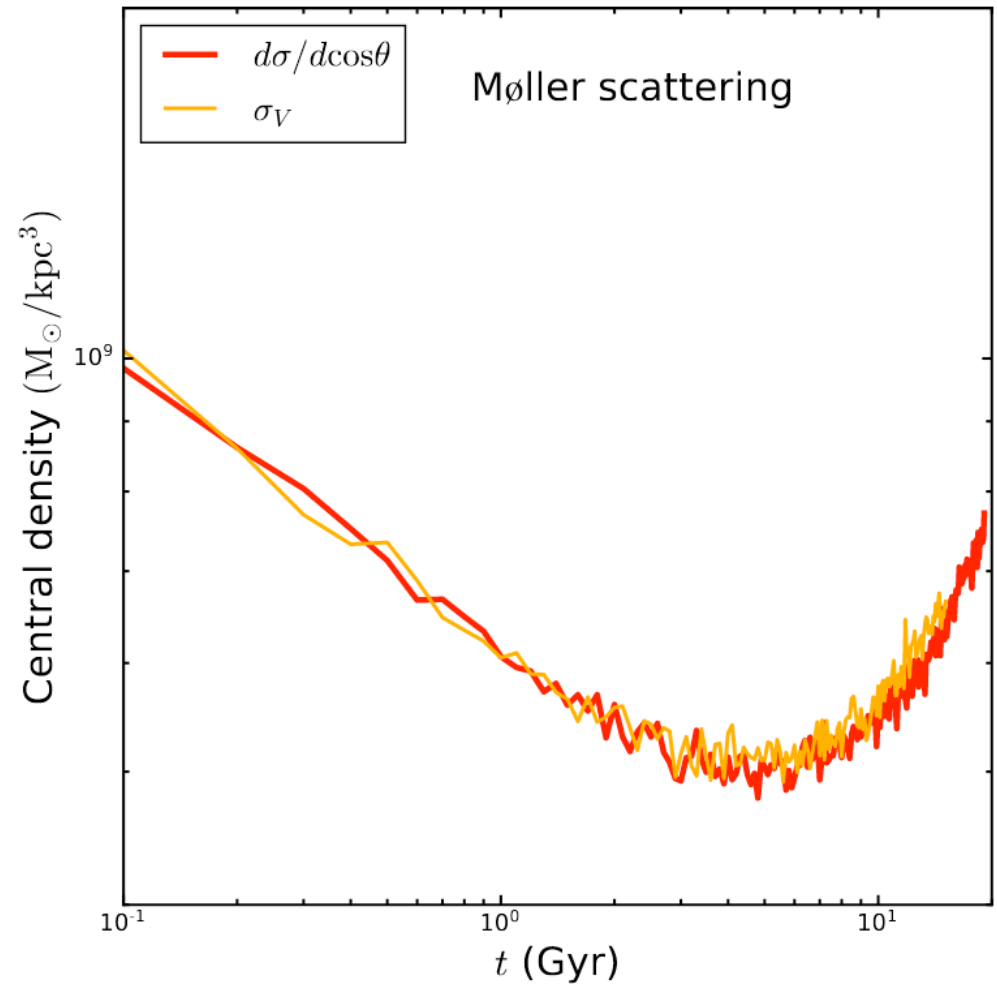
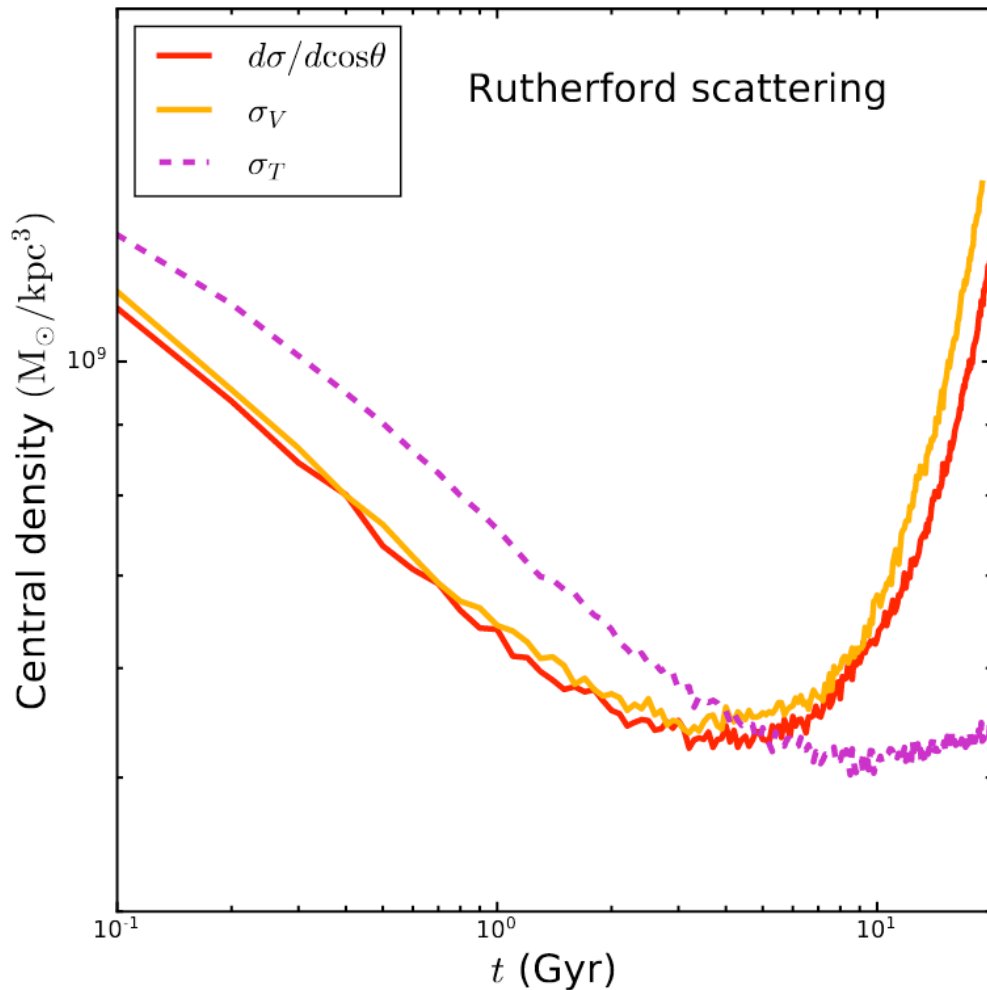
$$2K.E. + P.E. = 0$$

$$E_{\text{tot}} = -K.E. \quad \frac{E_{\text{tot}}}{T} < 0 \quad \text{Balberg+(ApJ 2002)}$$



GR instability conditions
 w/Feng, Zhong (ApJL 2021, JCAP 2022)

Settle the Debate with N-body Simulations



$$\sigma_V = \frac{3}{2} \int d\cos\theta \sin^2\theta \frac{d\sigma}{d\cos\theta}$$

viscosity/heat conduction

w/Tulin, Zurek (PRL, PRD 2013)

w/Yang (JCAP 2022)

Moller SIDM scattering:
Girmohanta, Shrock (2022)

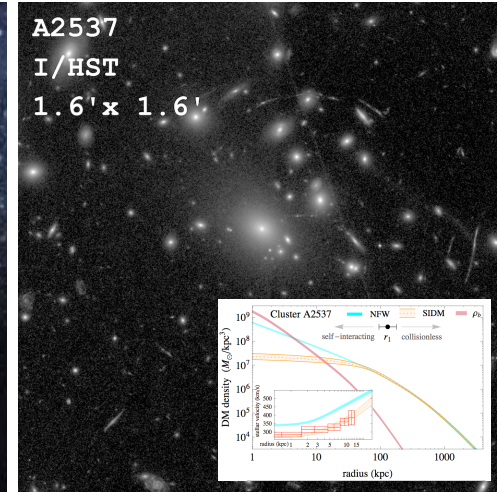
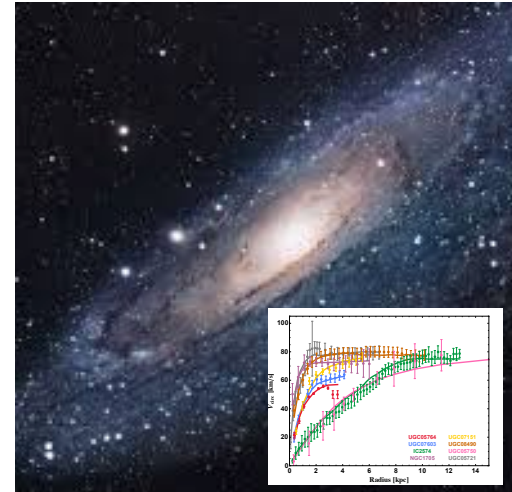
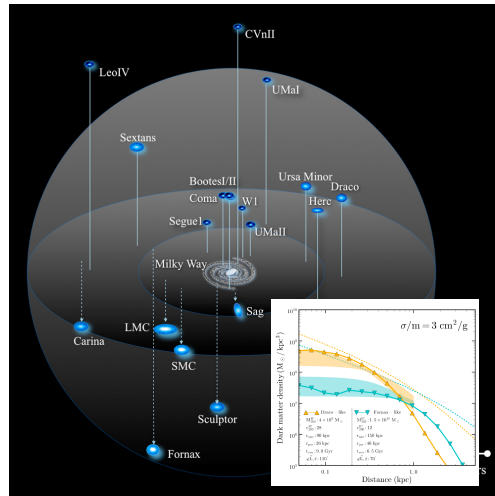
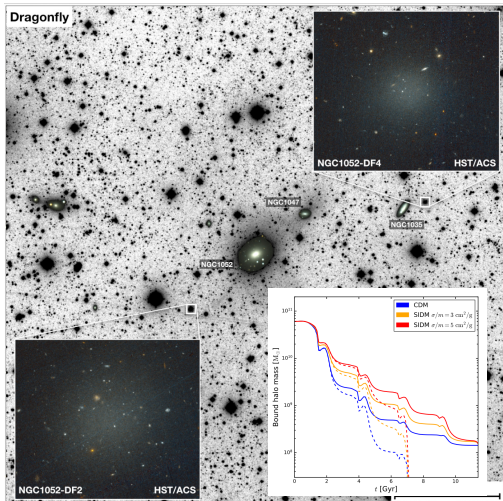
Cosmic Colliders of Dark Matter

Ultra-diffuse galaxies
(dark-matter-deficient)

Milky Way satellites

Spiral galaxies

Galaxy clusters



$$M_{\text{halo}} < \sim 10^8 M_\odot$$

$$M_{\text{halo}} \sim 10^8 M_\odot$$

$$M_{\text{halo}} \sim 10^9 - 10^{13} M_\odot$$

$$M_{\text{halo}} \sim 10^{15} M_\odot$$

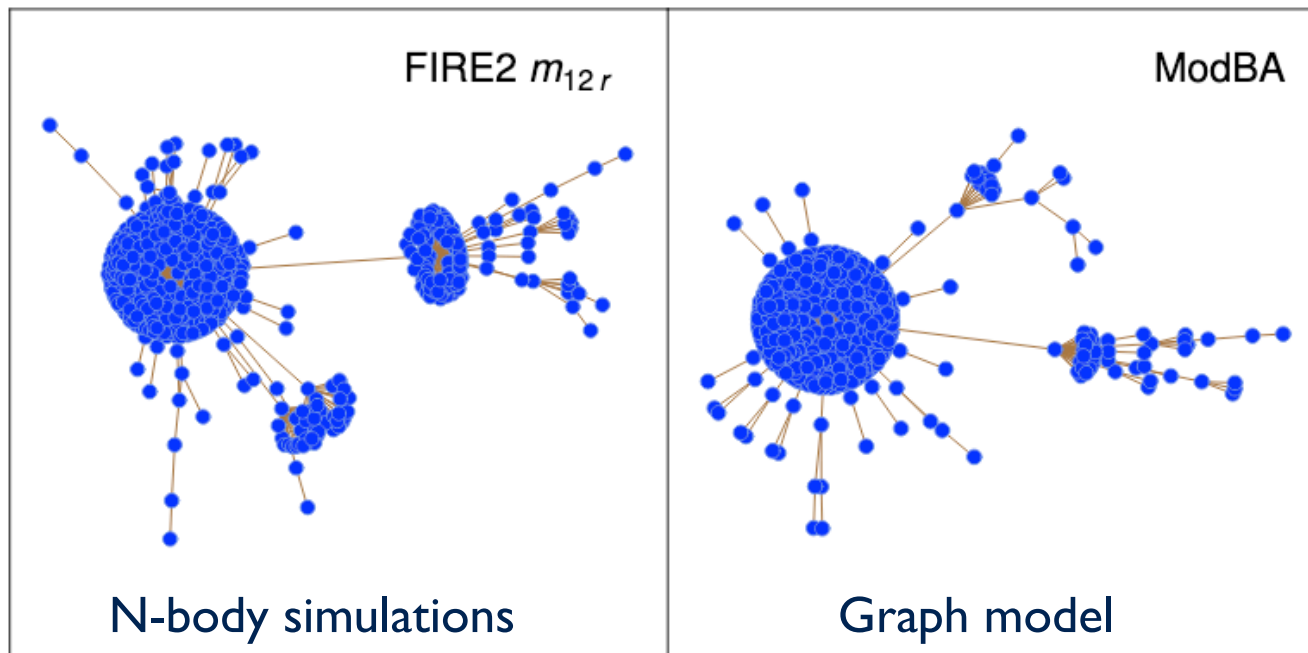
- Dark matter distributions of galaxies are more diverse than expected in CDM
- SIDM can produce the diversity
- DM self-interactions occur at fundamental scales $\sim 10^{-12} \text{ cm}$; change the dark matter distribution at astro scales $\sim 10^{22} \text{ cm}$, which can be detected!

Latest “Adventure” (Something that Rabi has not worked on)

A graph model for the clustering of dark matter halos

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(Dated: June 14, 2022)



- Graph models are constructed to explain “the rich gets richer”: the world-wide-web, e-mail, social, protein, and metabolic networks
- We apply a graph model to study hierarchical clustering of dark matter halos



Literally: a teacher for a day is a father for a lifetime

Actually: a teacher is as important as one's own father and therefore one should forever respect his teacher