DARK MATTER DETECTION INFORMED BY GALAXY FORMATION SIMULATIONS

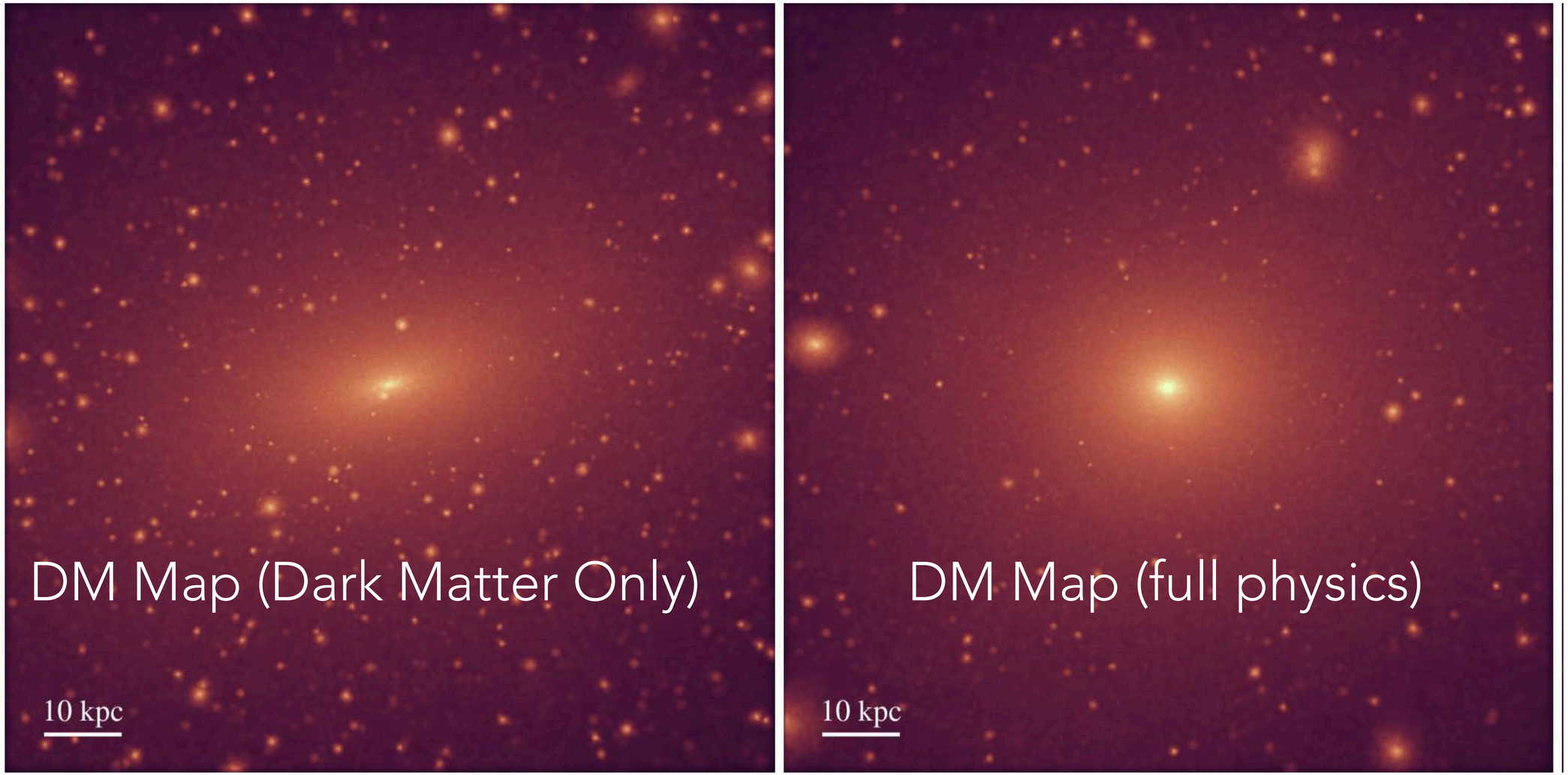

Image: Garrison-Kimmel et al. 2017

James Bullock (UC Irvine)

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

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Amplified J-factors in the Galactic Centre for velocity-dependent dark matter annihilation in FIRE simulations

Daniel McKeown [1]★ James S. Bullock [1] Francisco J. Mercado [1] Zachary Hafen [1] Michael Boylan-Kolchin [2] Andrew Wetzel [3] Lina Necib [4] Philip F. Hopkins [4] and Sijie Yu [1]

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Sliding into DM: Estimating the local dark matter density and velocity distribution from simple observables

Patrick G. Staudt,[1] James S. Bullock,[1] and the FIRE Collaboration

[1] *Department of Physics and Astronomy, University of California, Irvine, California 92697*

FIRE-2 simulations of Milky Way-mass galaxies

Feedback In Realistic Environments

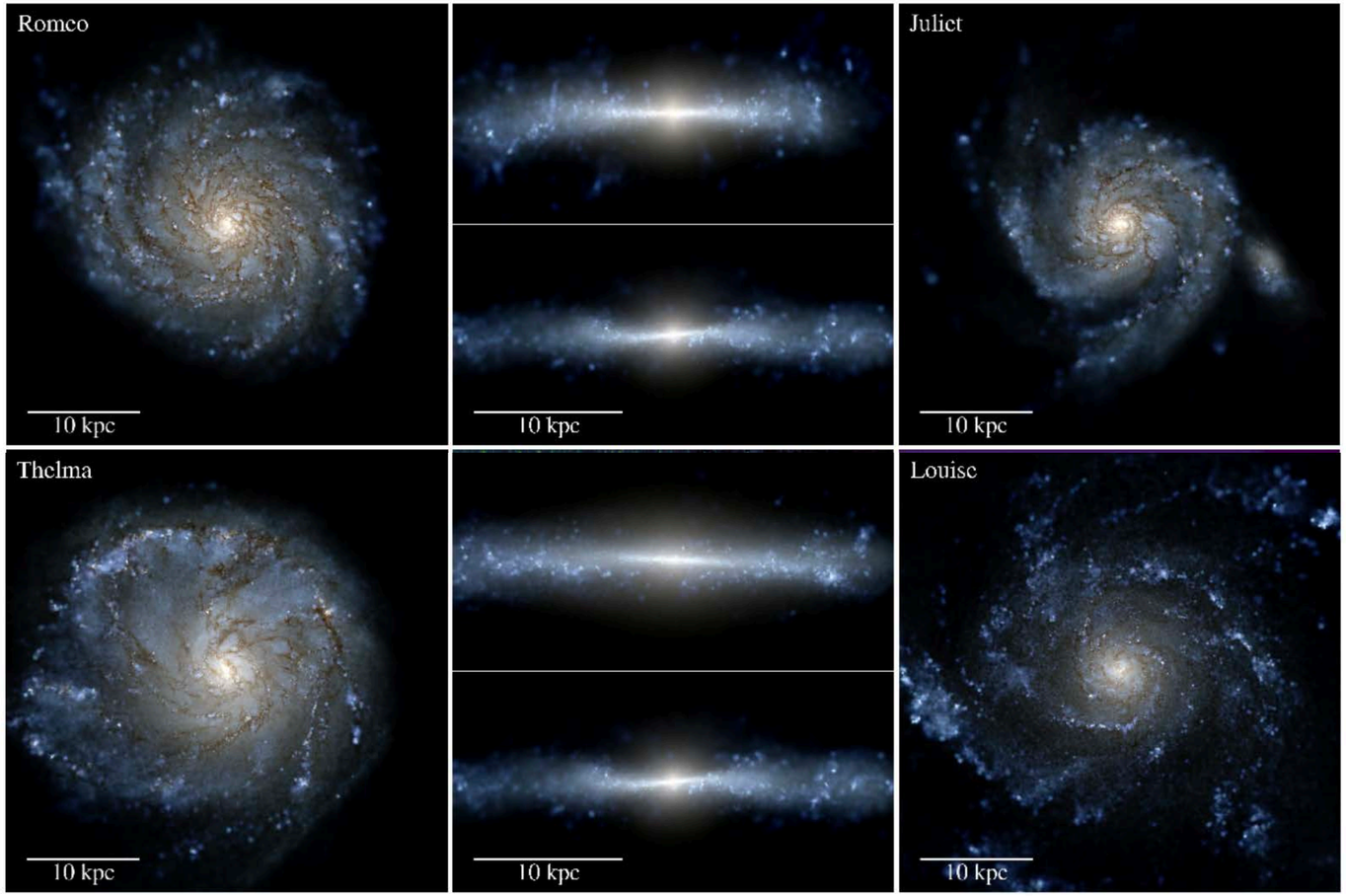
Image: Garrison-Kimmel et al. 2018

12 MW-size galaxies galaxies

M_{vir} = 0.8-1.6e12 M_{sun}

M_{*} = 3-10.e10 M_{sun}

~100M DM particles per halo



Resolve central ~400pc of galactic center (<3 degrees)

Outline

1. Indirect detection:
- Amplified Galactic J-factors
(**McKeown** et al. 2022)

2. Direct detection:
- Estimating local DM density
- Local velocity distribution
(**Staudt** et al. 2023)

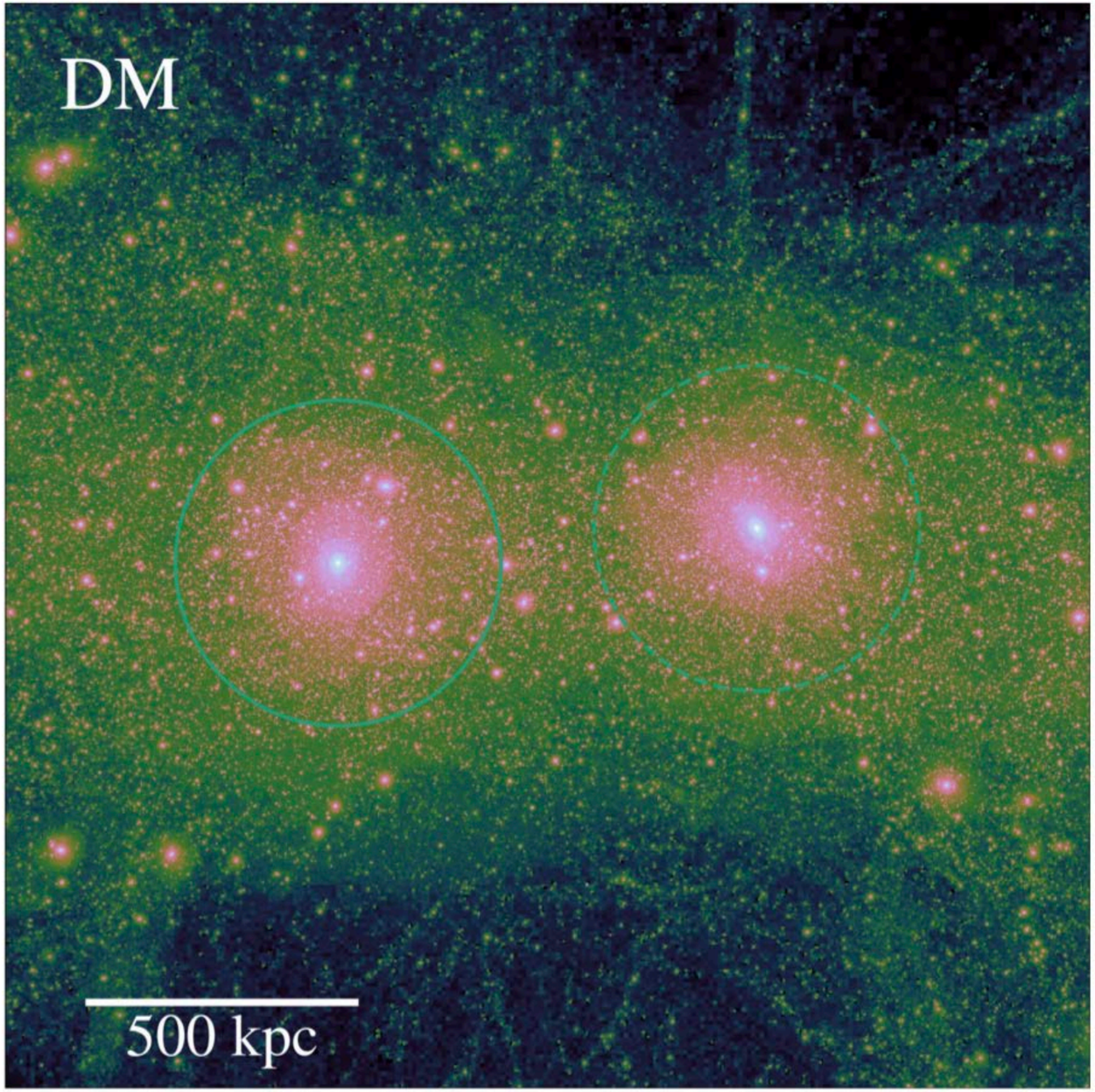


Image: Garrison-Kimmel et al. 2018

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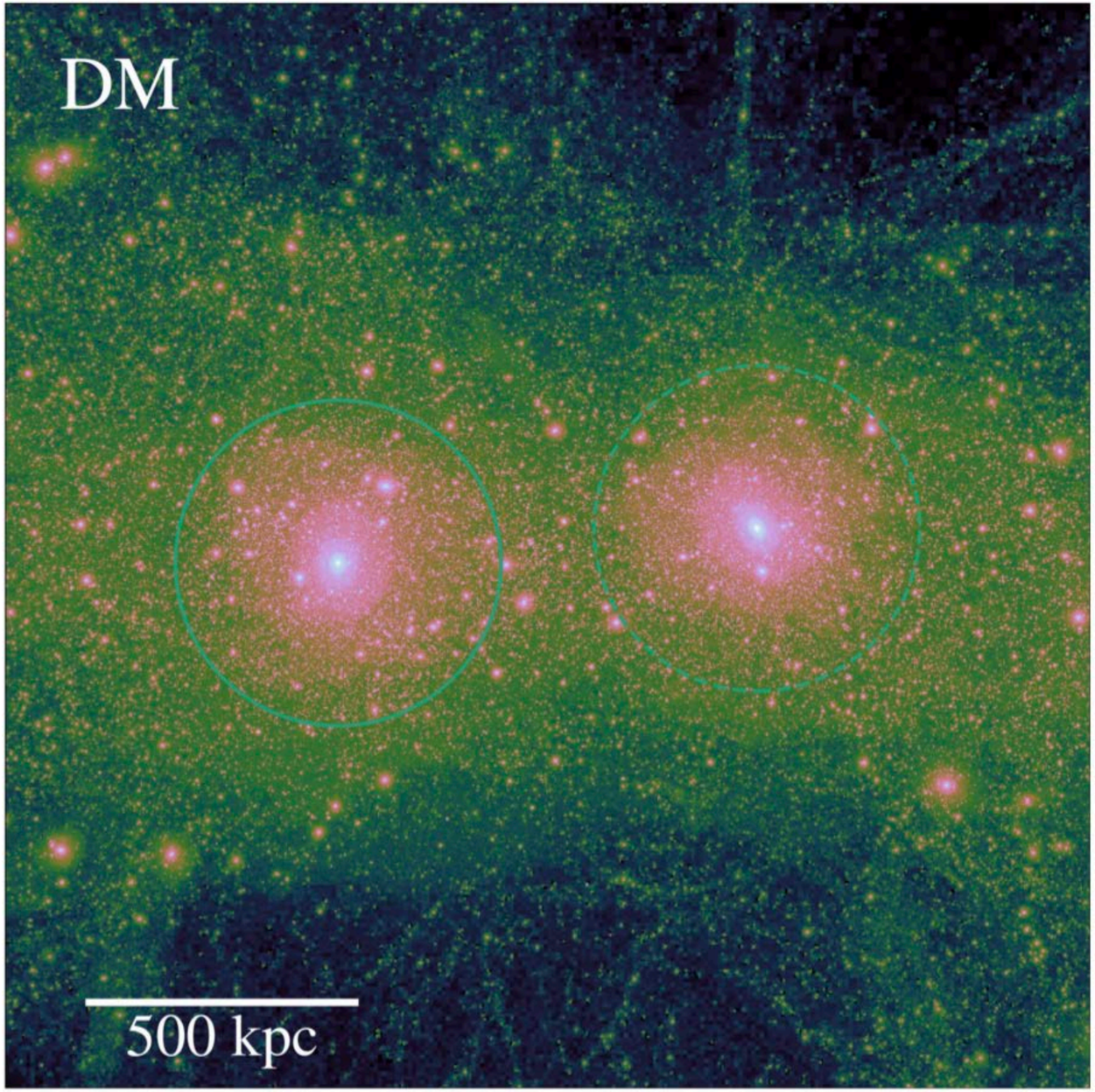

Image: Garrison-Kimmel et al. 2018

Fermi Galactic Center excess in γ-rays

Annual Review of Nuclear and Particle Science

The *Fermi*–LAT Galactic Center Excess: Evidence of Annihilating Dark Matter?

Simona Murgia

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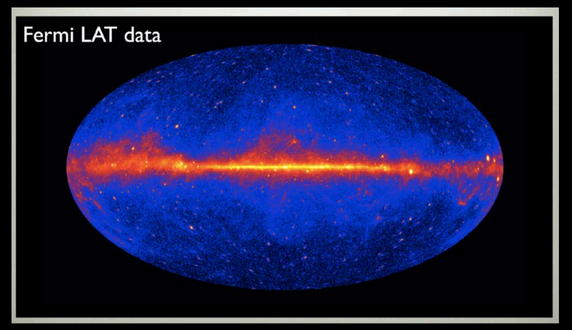
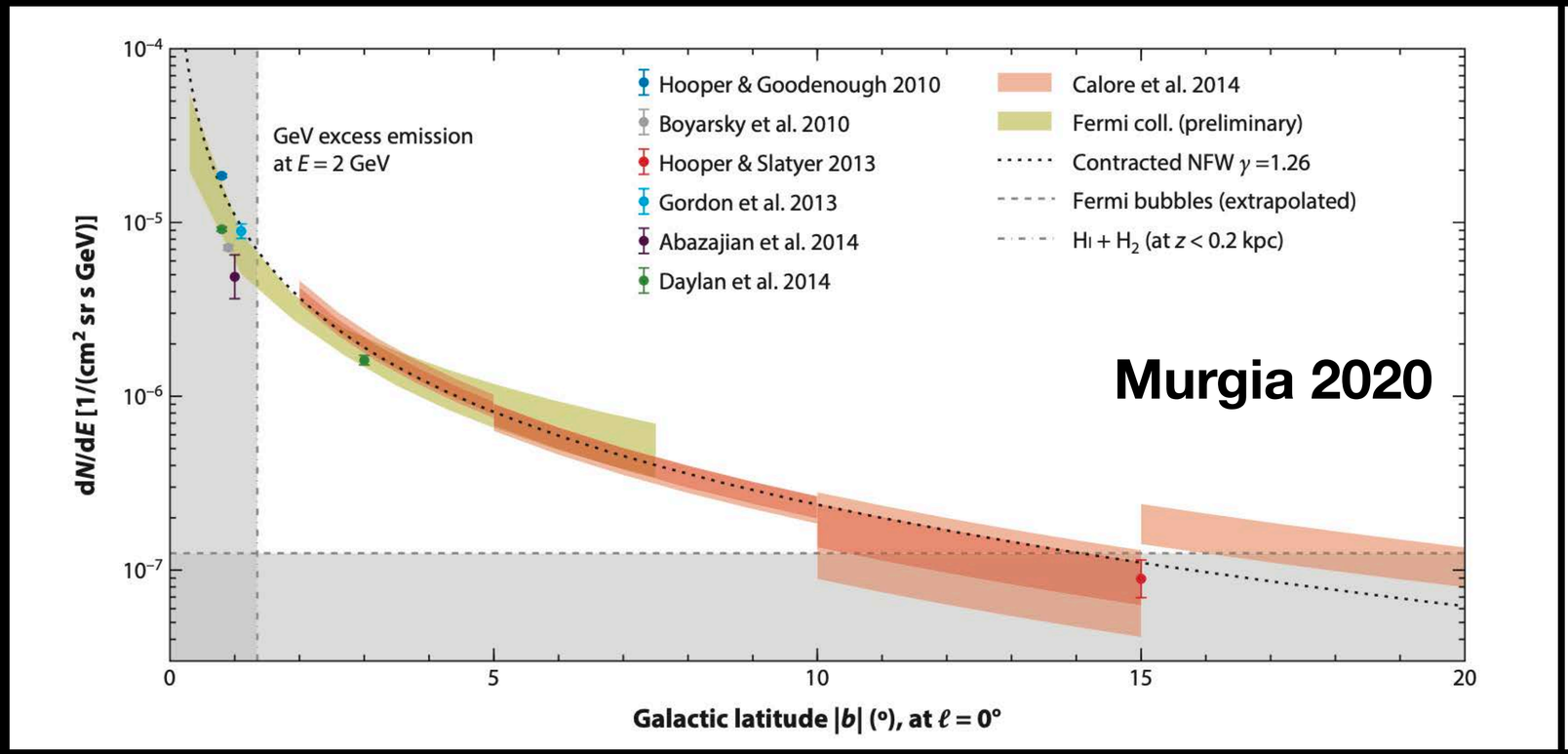
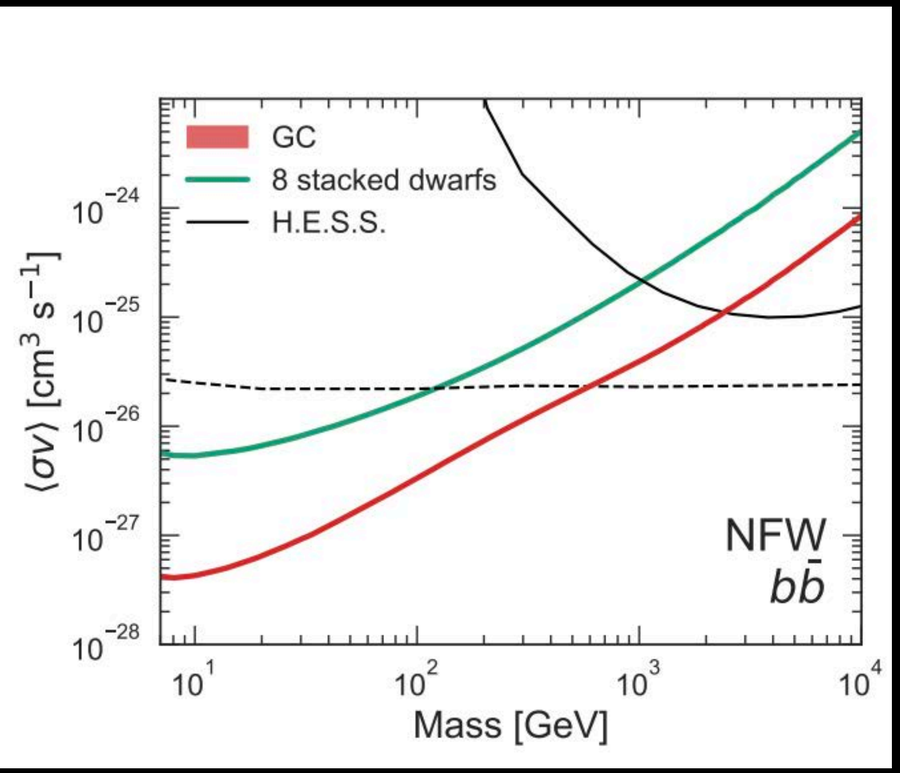
- Consistent w DM particle ~50 GeV w/ thermal cross section.
- Other interpretations possible. Could be unresolved point sources, e.g. millisecond pulsars.



- Shape of emission seems more consistent w/ stellar population?





From Abazajian et al 2020

See: Tracy Slatyer's talk yesterday

Velocity-dependent annihilation cross section?

$$\frac{d^2\Phi}{dE_\gamma d\Omega} = \frac{(\sigma_A v)_0}{8\pi m_X^2}\frac{dN}{dE_\gamma}J_Q(\theta)$$

Generalized astrophysical J factor
(v/c~3.e-4 in GC)

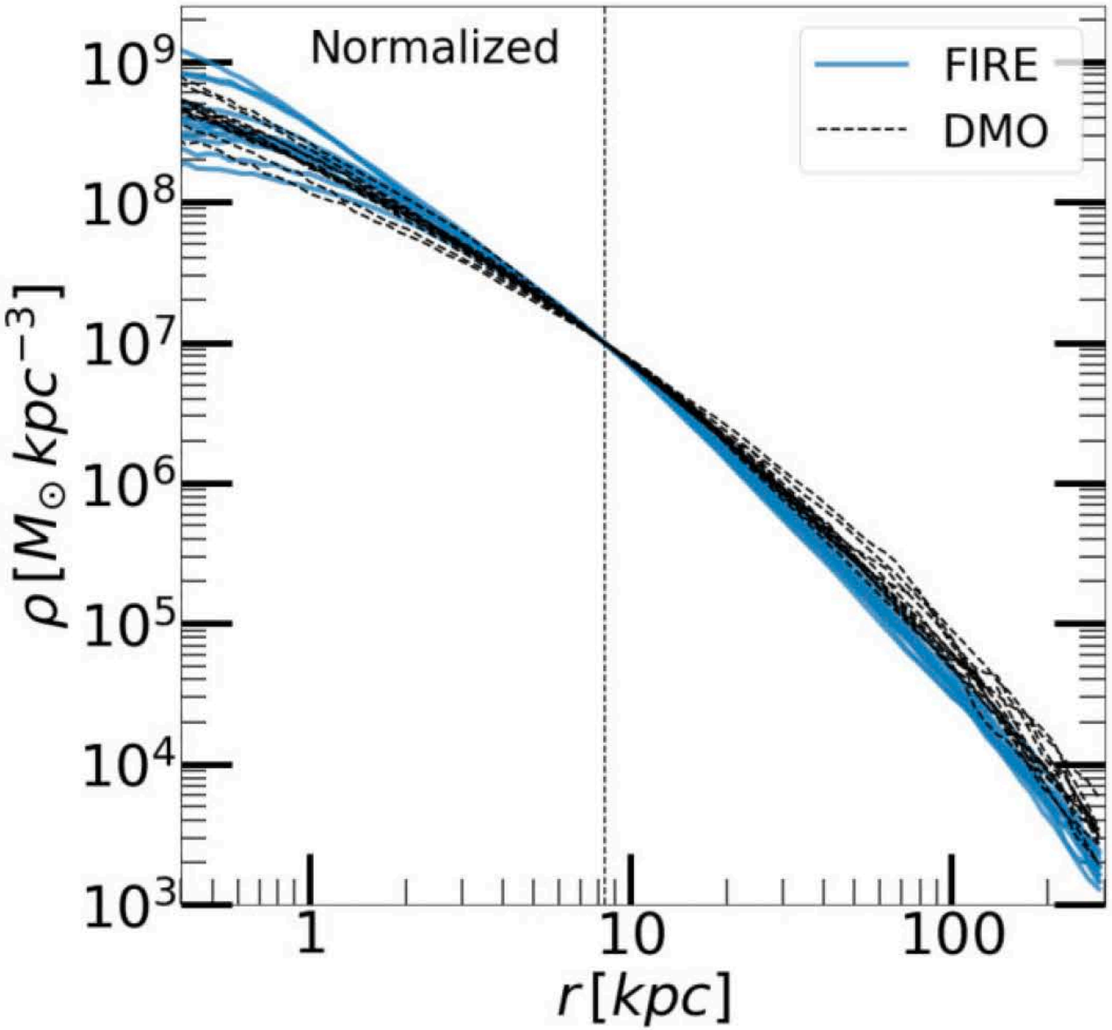
S-wave: $\sigma v \propto$ **const.** $J_s(\theta) = \frac{1}{c^2}\int dl[\rho(\vec{r})]^2$

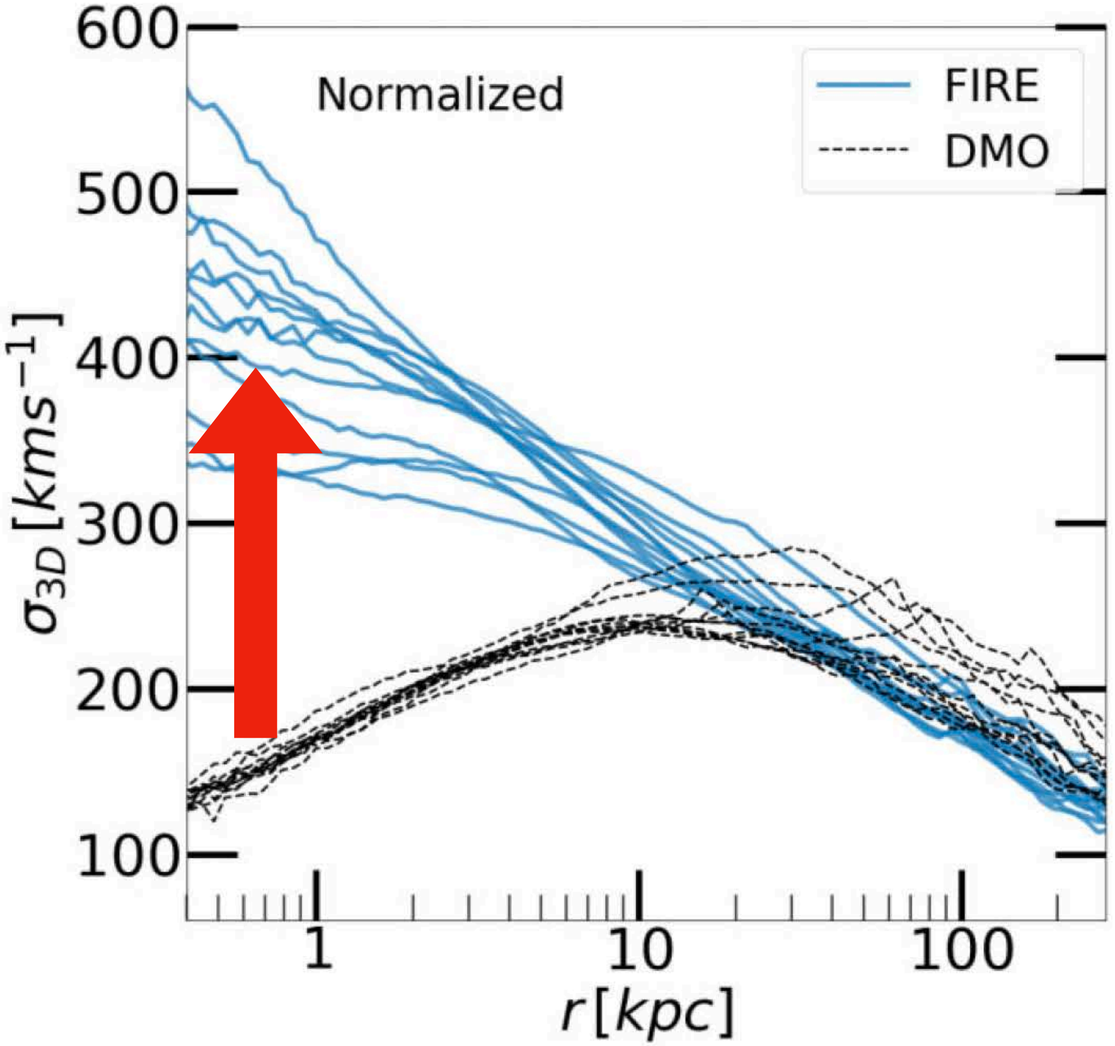
P-wave: $\sigma v \propto (v/c)^2$ $J_p(\theta) = \frac{1}{c^2}\int dl[\rho(\vec{r})]^2\mu_2(\vec{r})$

D-wave: $\sigma v \propto (v/c)^4$ $J_p(\theta) = \frac{1}{c^2}\int dl[\rho(\vec{r})]^2\mu_4(\vec{r})$

(c.f. Robertson & Zentner 2009 ; Giacchino, Lopez-Honorez & Tytgat 2013 ; Choquette, Cline & Cornell 2016 ; Boddy, Kumar & Strigari 2018 ; Petac, Ullio & Valli 2018 ; Arguelles et al. 2019 ; Johnson et al. 2019 ; Board et al. 2021)

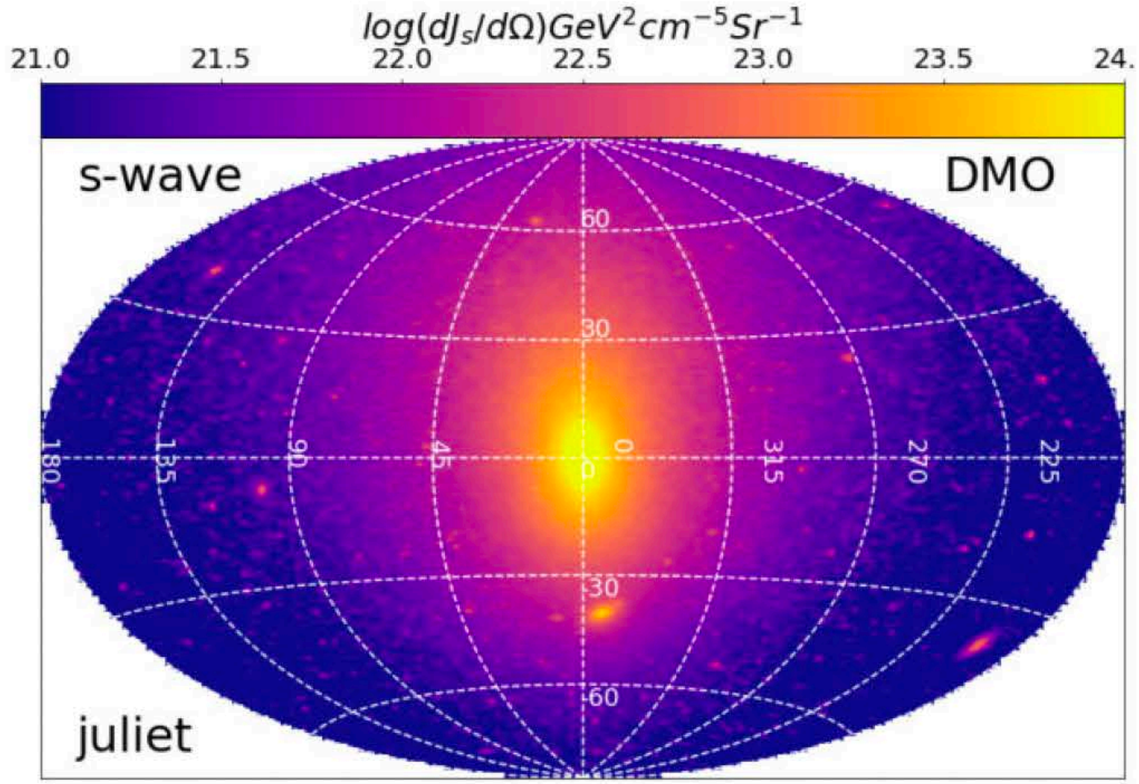
Galaxy Formation boosts DM velocity dispersion

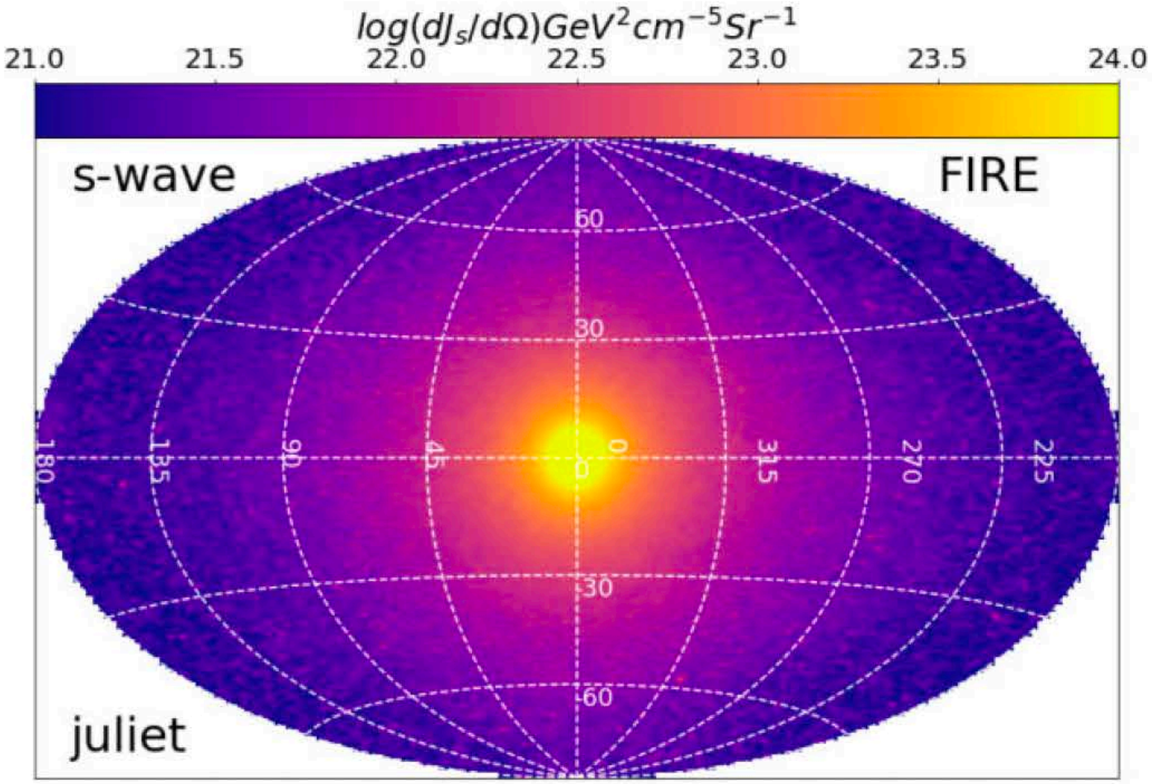




McKeown et al. 2022

S-wave: $\sigma v \propto$ const.





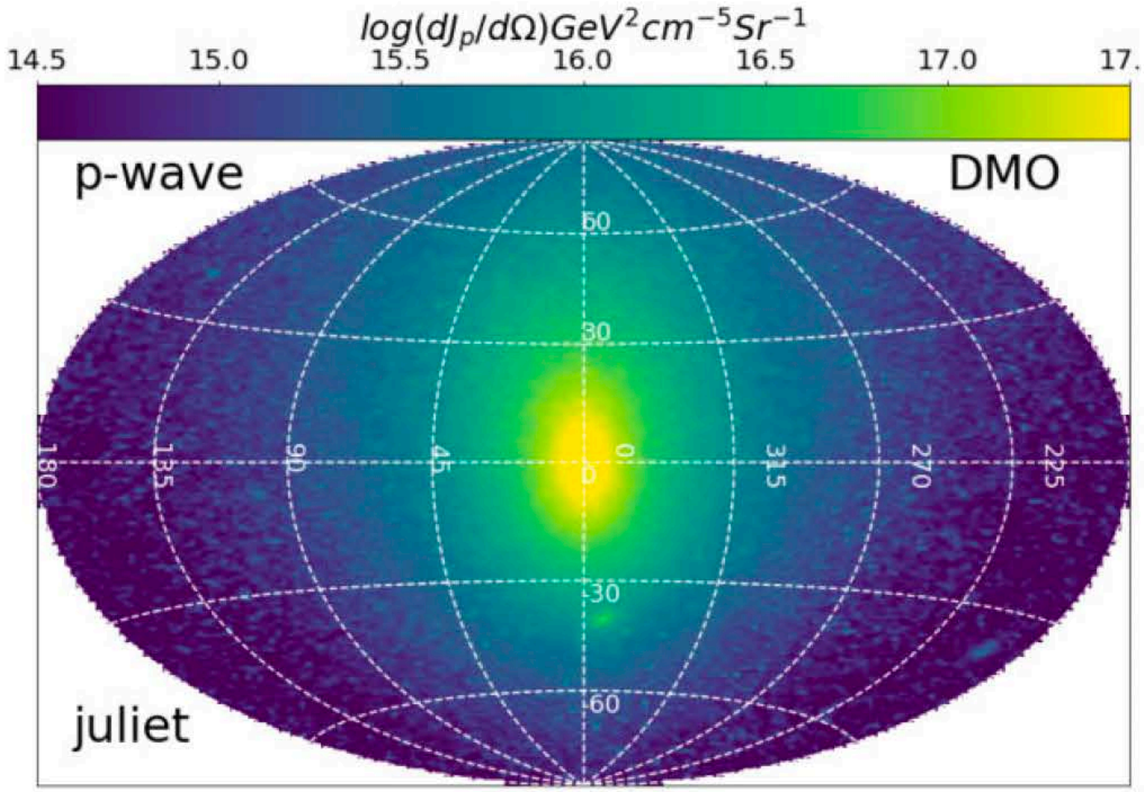
Dark Matter Only

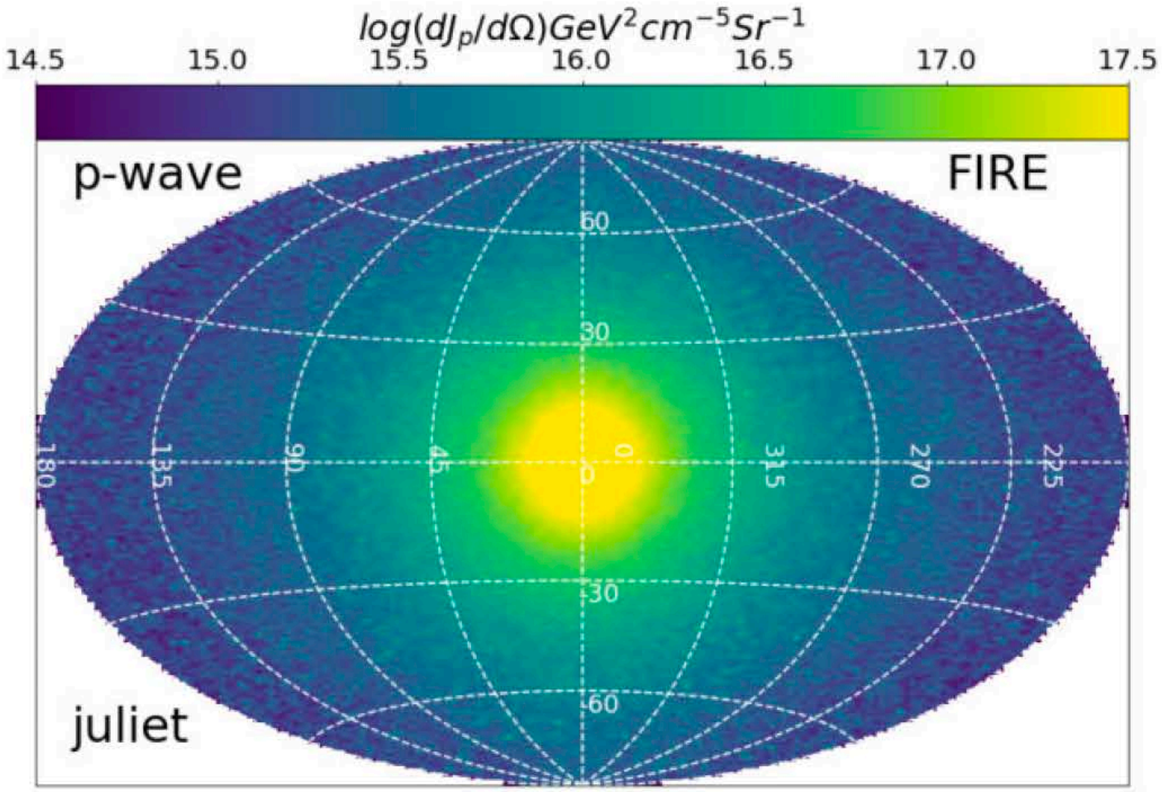
Full physics

- No substructure
- Rounder emission

McKeown et al. 2022

p-wave: $\sigma v \propto (v/c)^2$





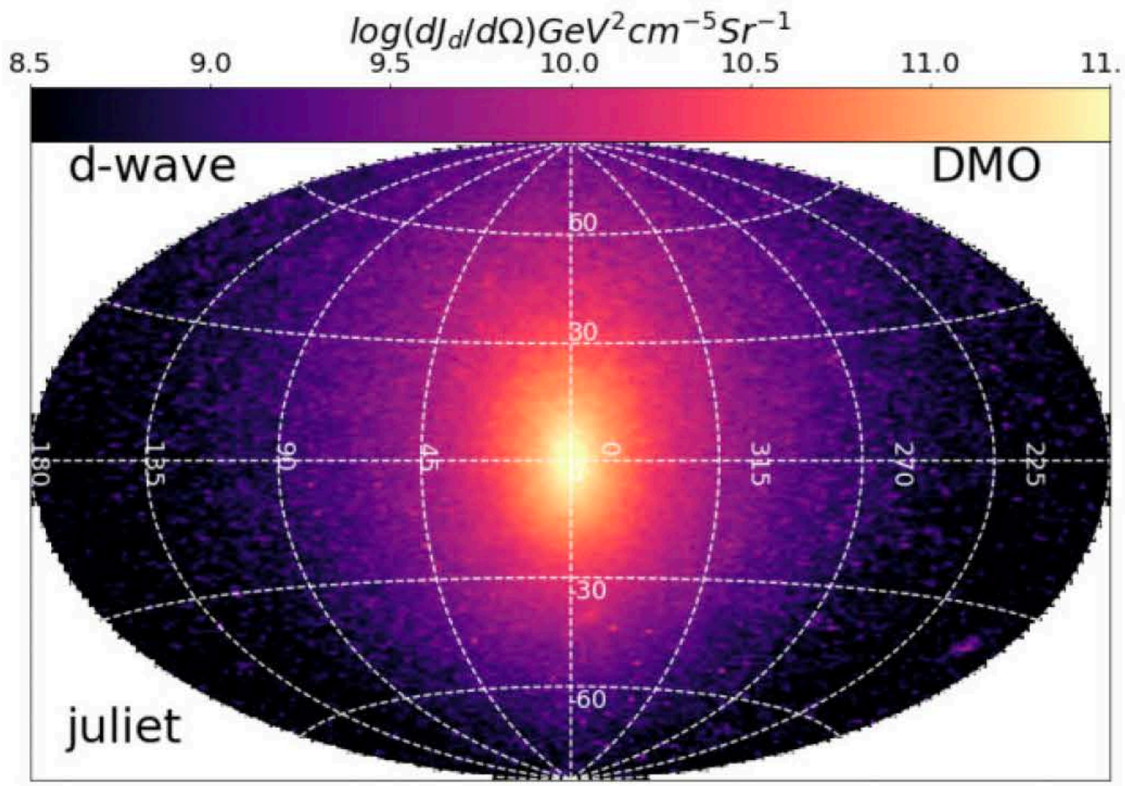
Dark Matter Only

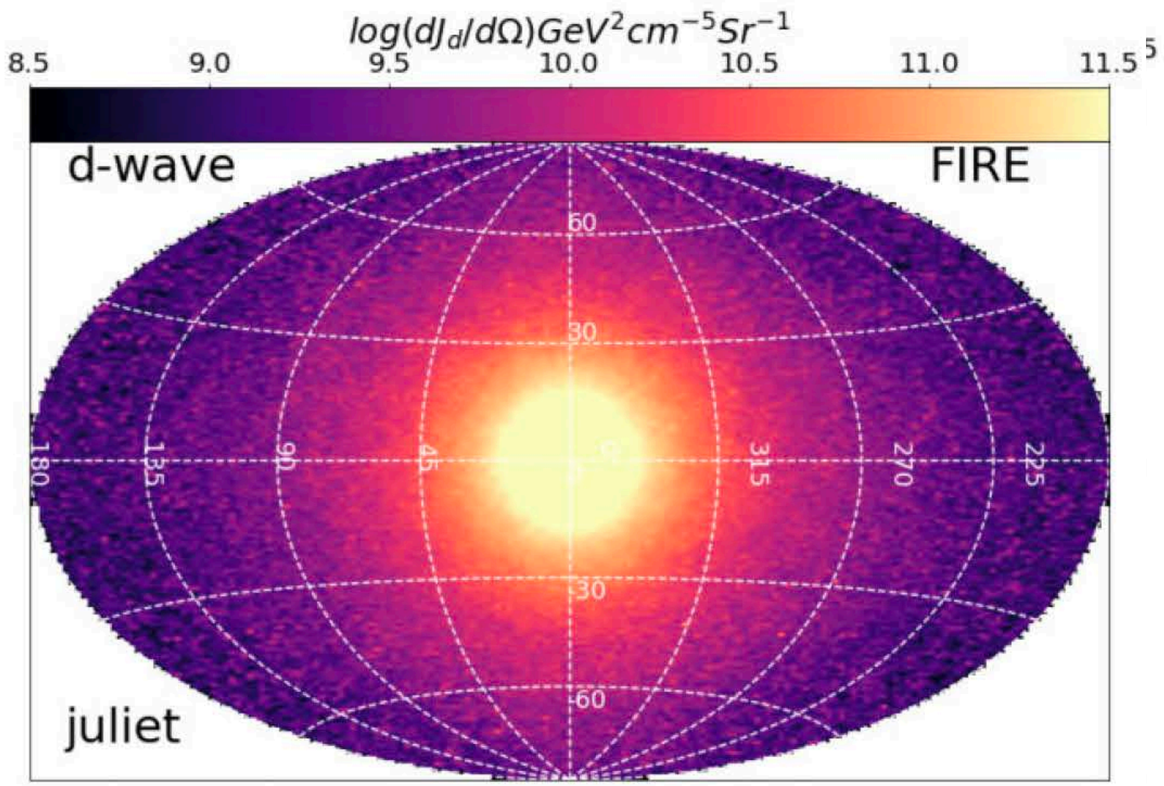
Full physics

- Brighter (~ 10 times)
- Rounder emission

McKeown et al. 2022

d-wave: $\sigma v \propto (v/c)^4$





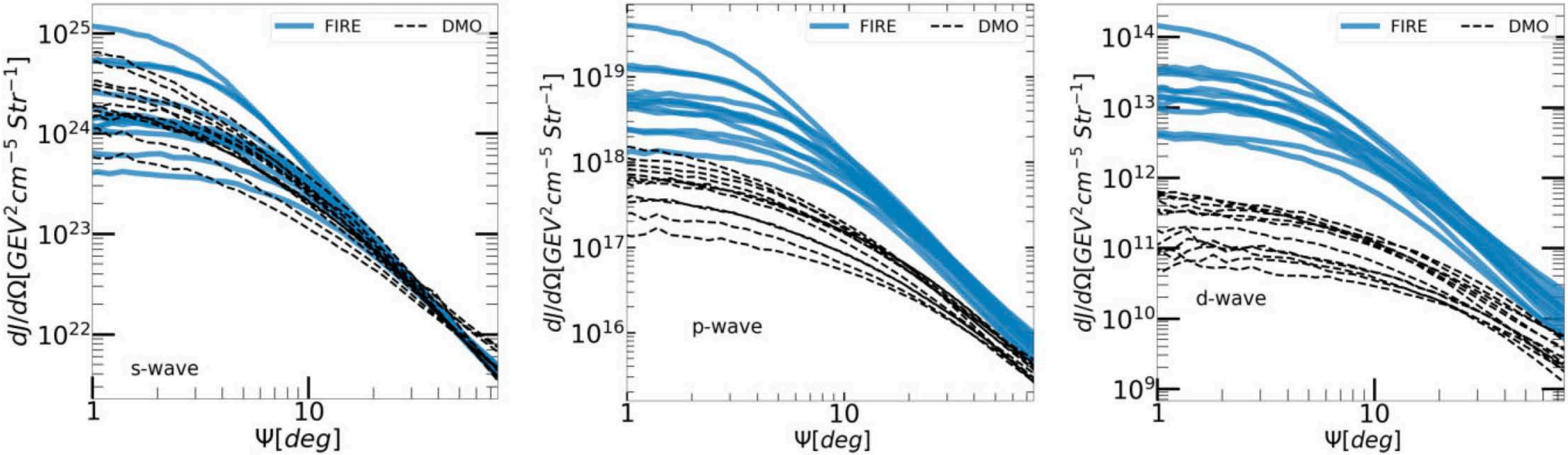
Dark Matter Only

Full physics

- MUCH Brighter (~ 100 times)
- Rounder emission

McKeown et al. 2022

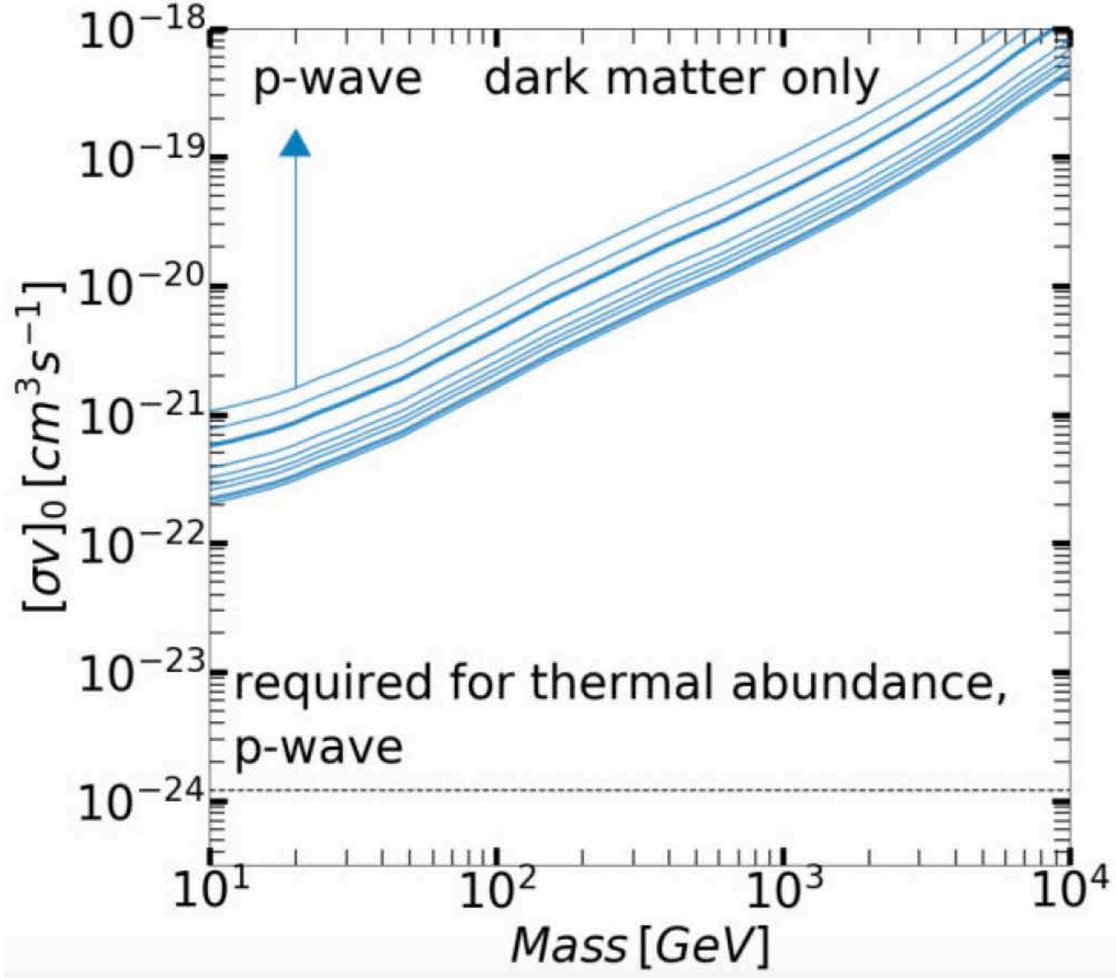
Emission more varied & centrally concentrated In full physics simulations

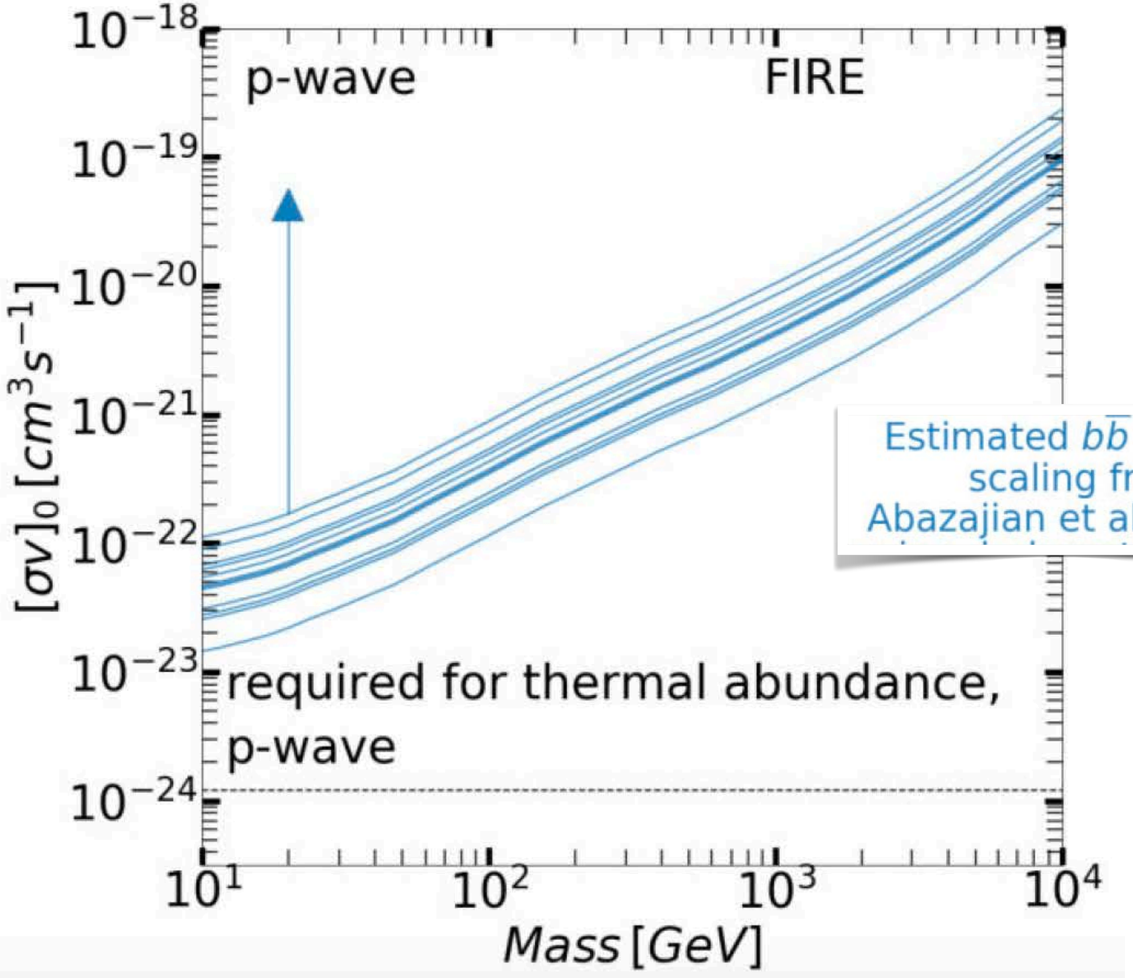


McKeown et al. 2022

See also: Board et al. 2021

P-wave constraints: much closer to thermal cross section





McKeown et al. 2022

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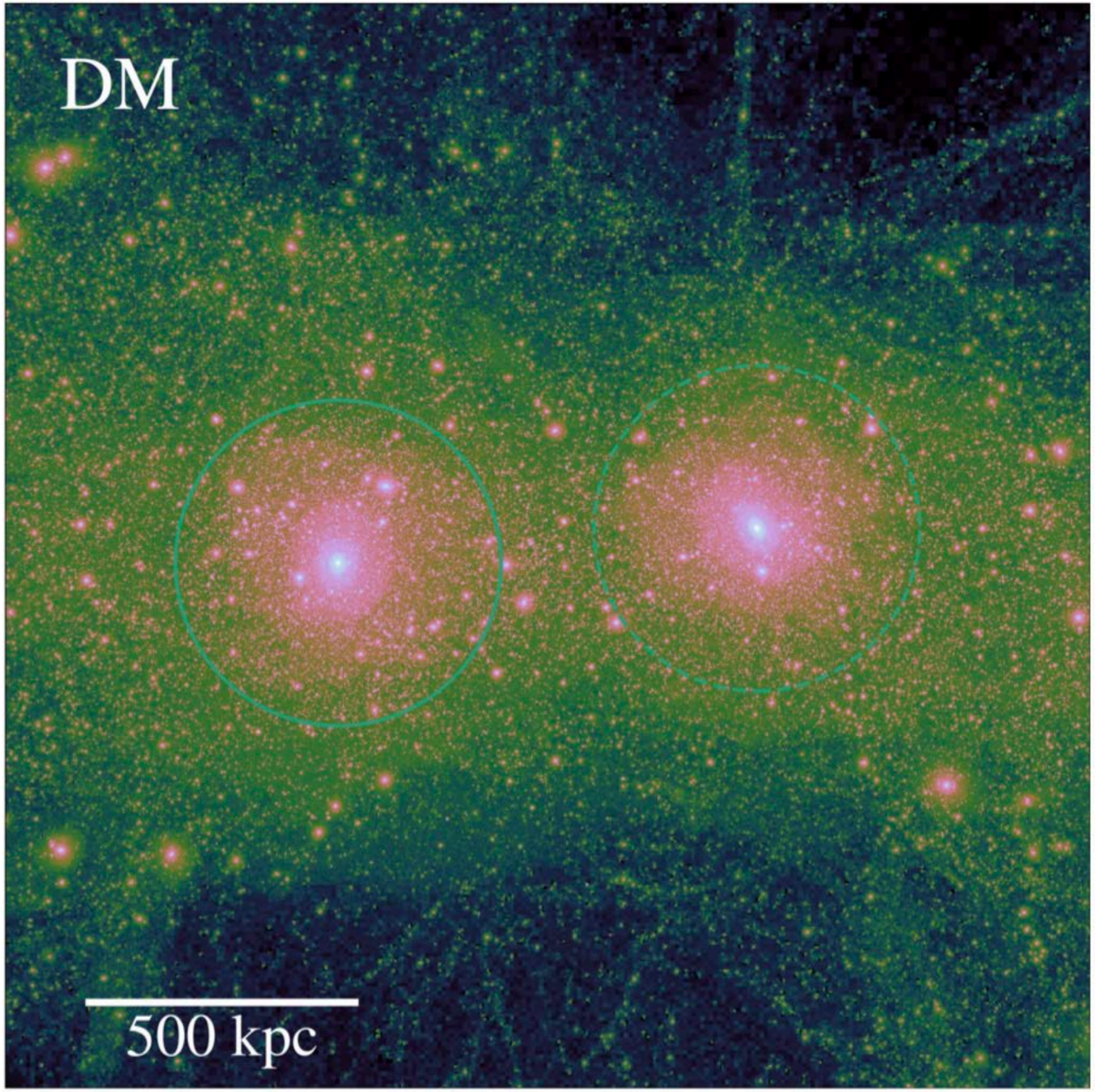
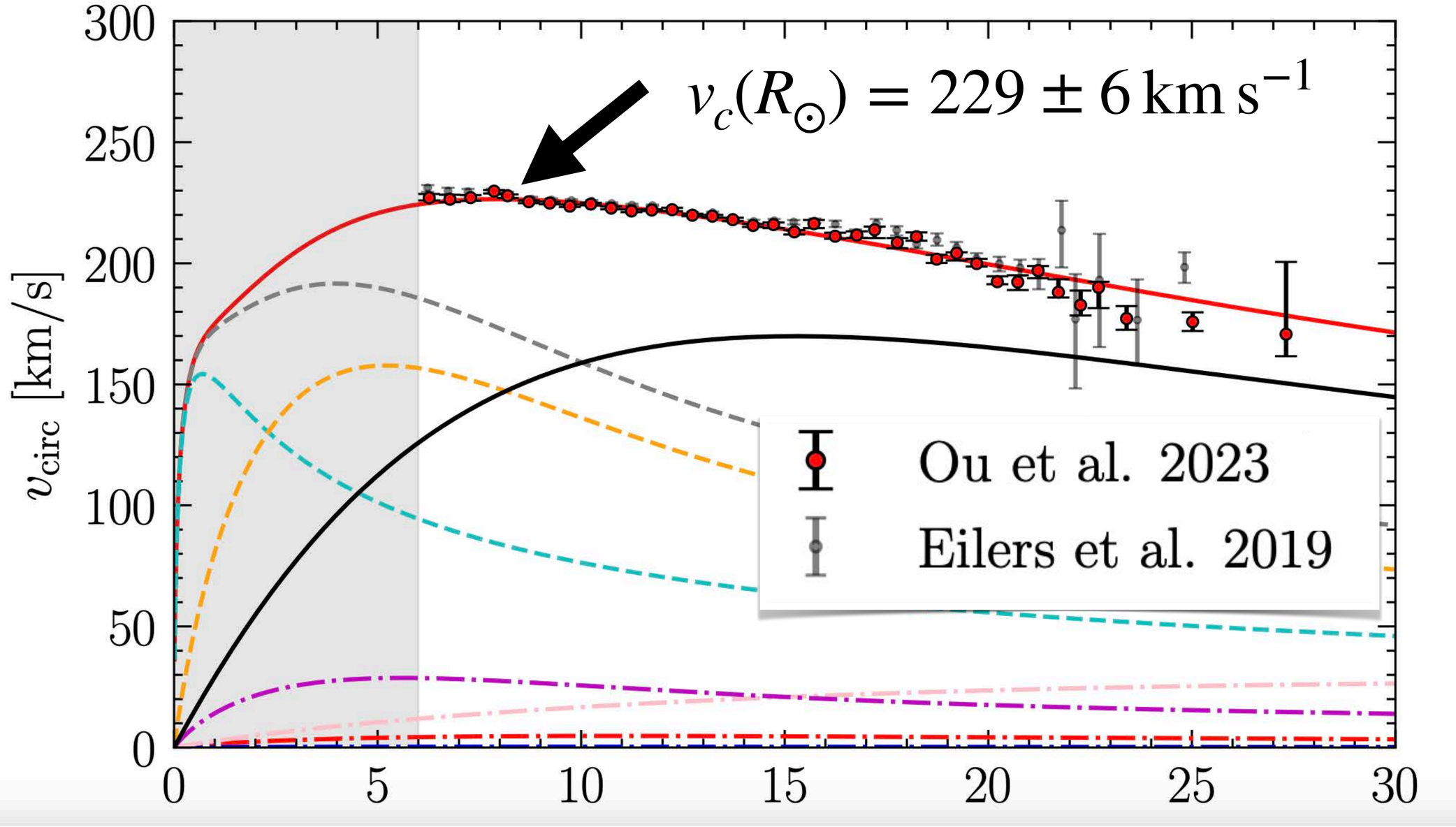


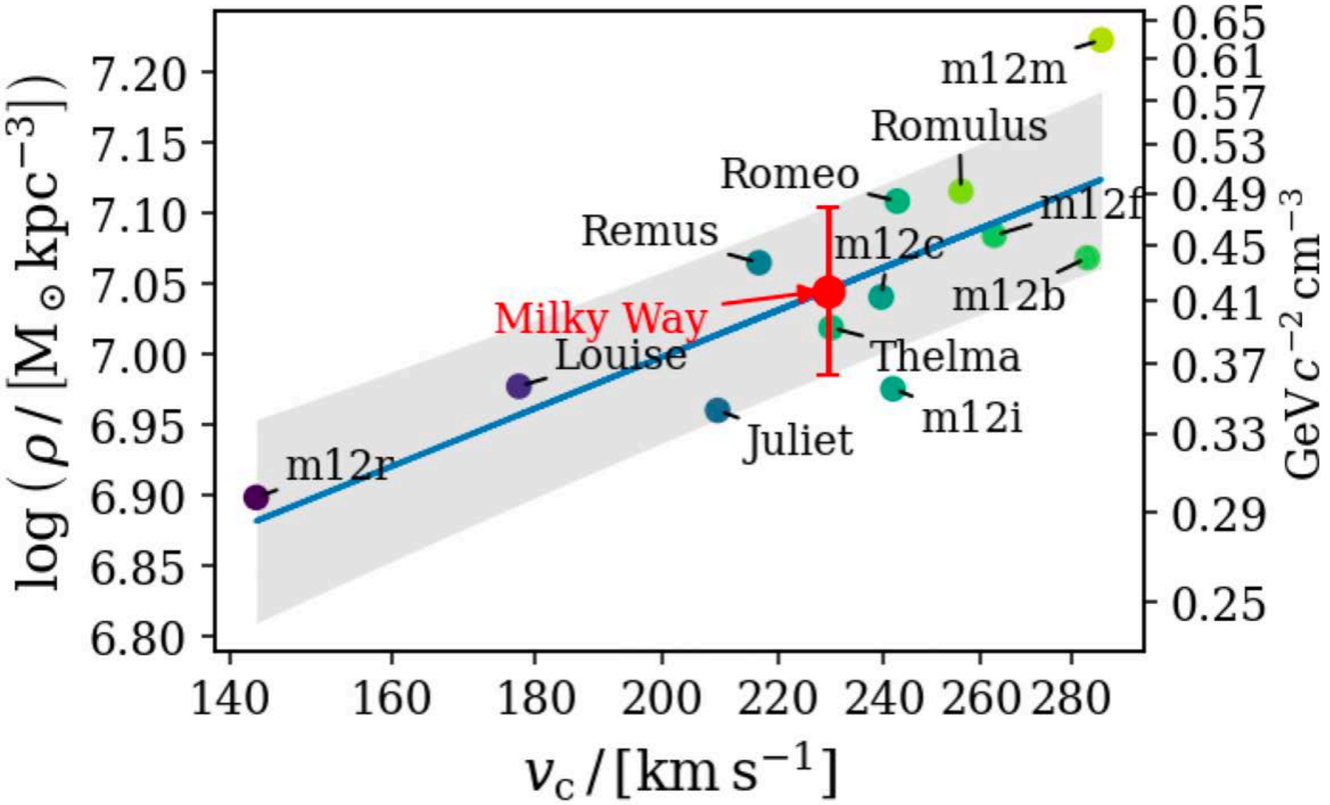
Image: Garrison-Kimmel et al. 2018

Vc at solar radius known extremely well

APOGEE, WISE, 2MASS,Gaia.



Find tight correlation w/ local DM density & Vc



$$\rho = \rho_0 \left(\frac{v_c}{100\,\mathrm{km\,s}^{-1}}\right)^{\alpha} \qquad \alpha = 0.8 \pm 0.2$$

$$\rho_0 = 0.57\ {}^{+0.11}_{-0.09}\ 10^7 \mathrm{M}_\odot\,\mathrm{kpc}^{-3}$$

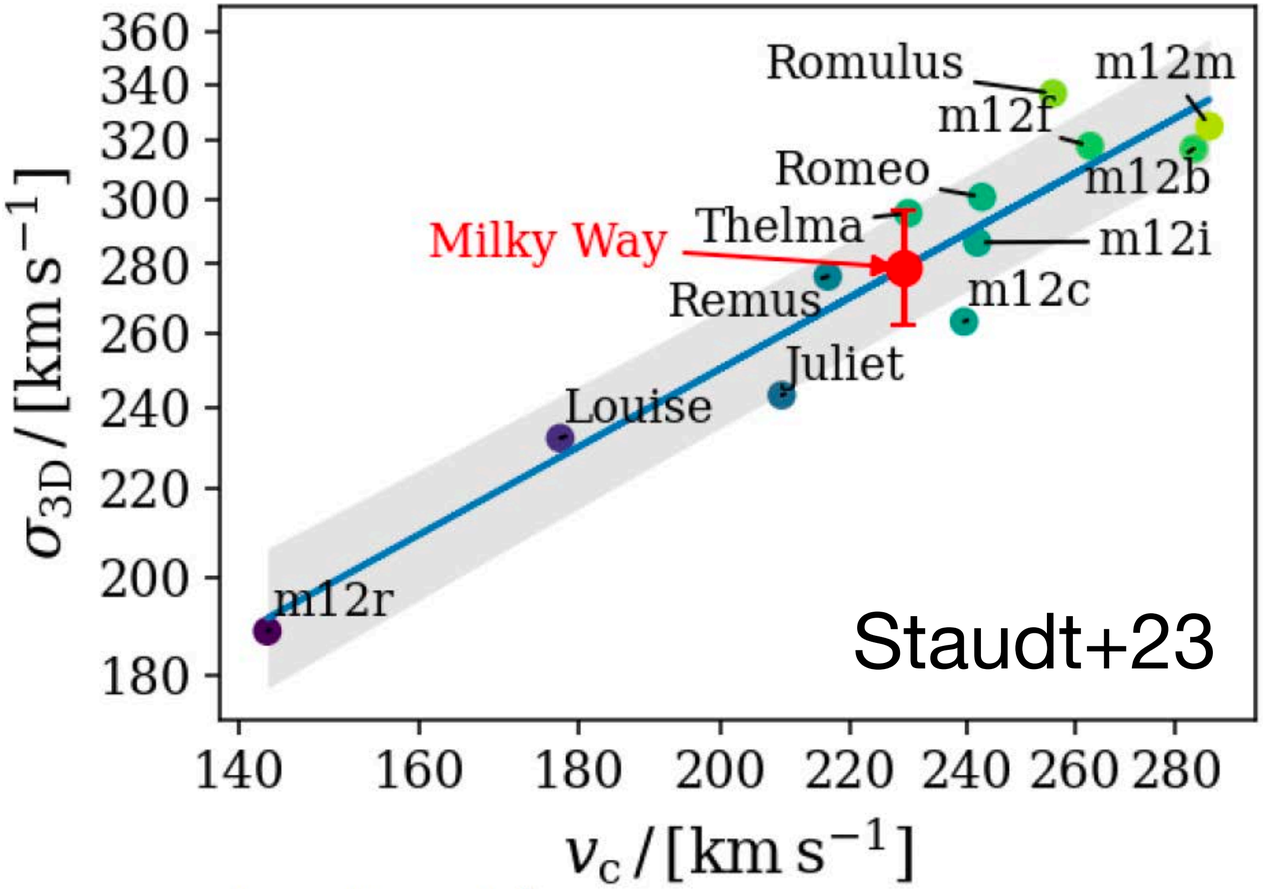
Observed V_c = 229 km/s => DM density near Earth

$$\rho_{\mathrm{DM}}(R_\odot) = 0.42 \pm 0.05\,\mathrm{GeV\,cm}^{-3}$$

Staudt+23

Recent estimates range from 0.3-0.6 Gev/cm^3 (e.g. deSales+19, Benito+21)

Local DM velocity dispersion also correlates w/ Vc



$$\sigma_{3D} = \sigma_0 \left(\frac{v_c}{100\,\mathrm{km\,s^{-1}}} \right)^{\gamma}$$

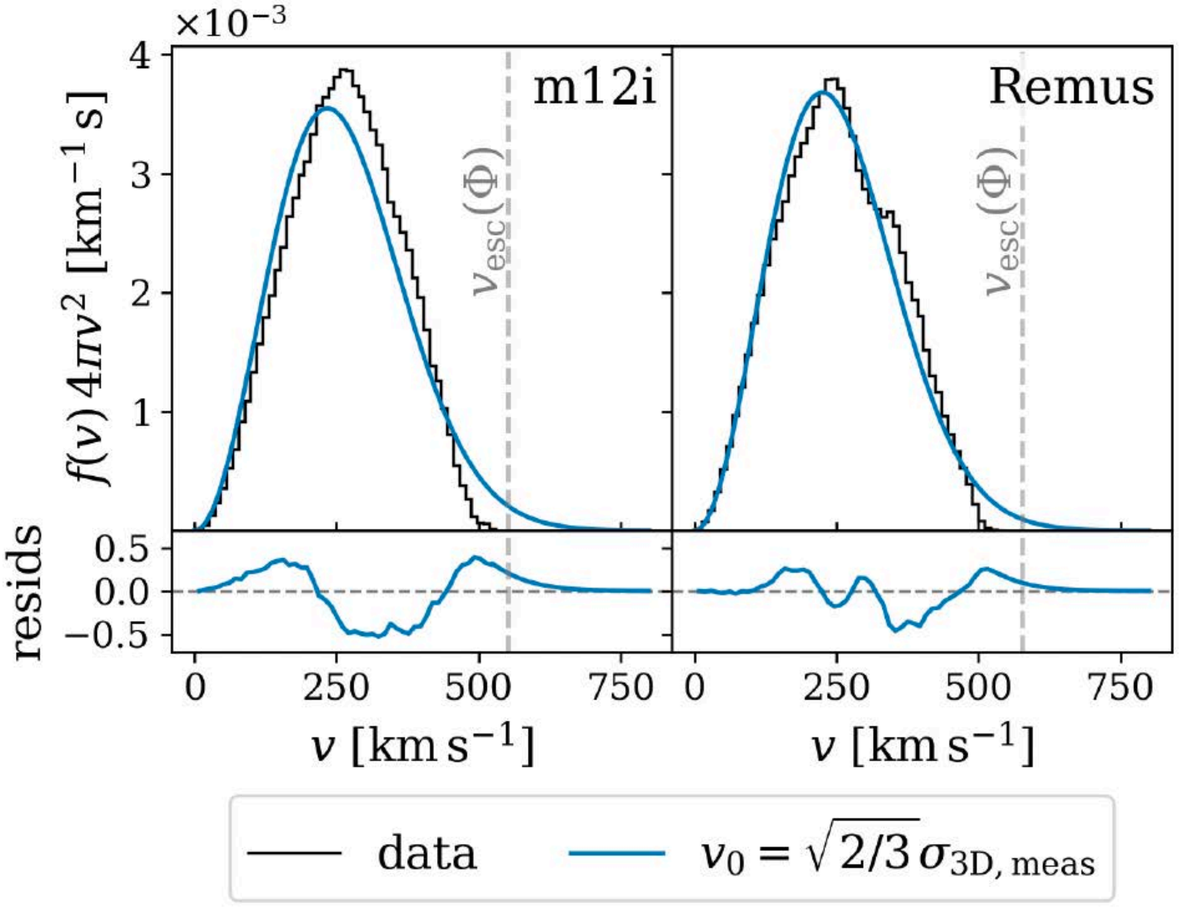
$\sigma_0 = 143 \pm 11\,\mathrm{km\,s^{-1}}$ and $\gamma = 0.80 \pm 0.09$;

Observed V_c = 229 km/s =>
DM velocity dispersion near Earth

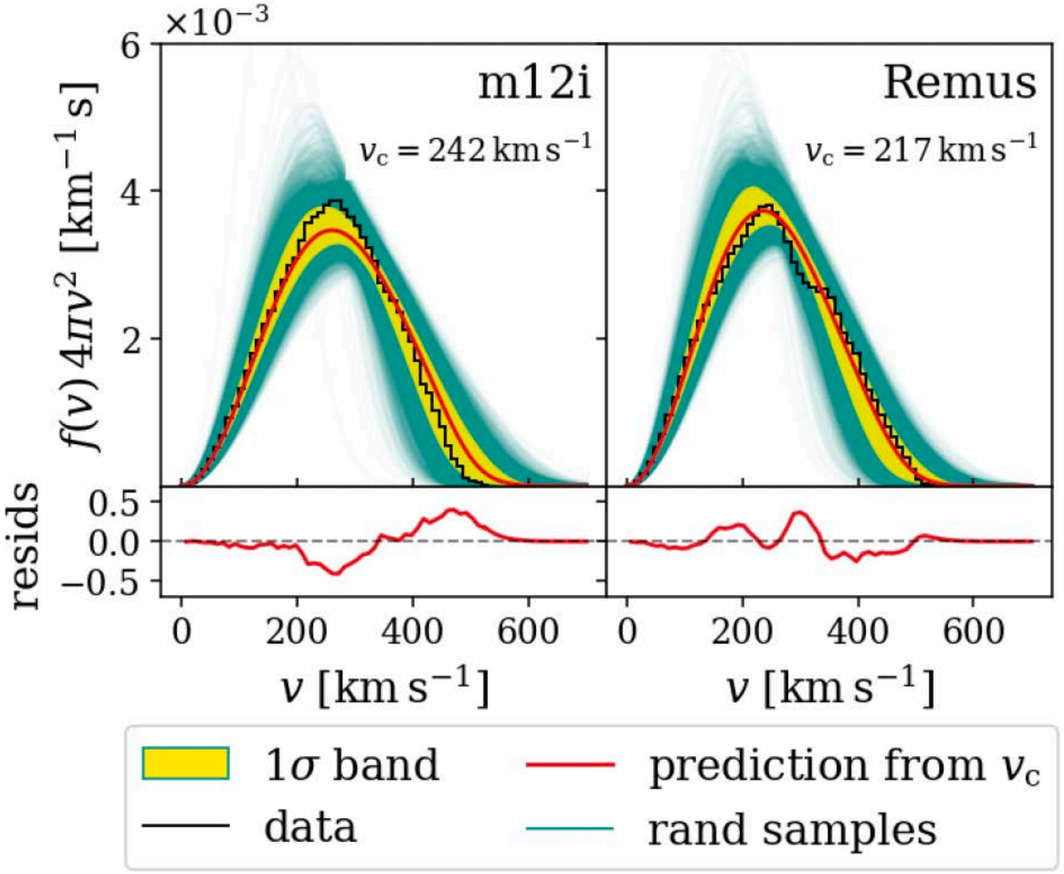
$$\sigma_{3D,DM}(R_\odot) = 279 \pm 18\,\mathrm{km\,s^{-1}}$$

People often **assume** $\sigma^2 = 3v_c^2/2$
=> σ ~ 280, so ~consistent

SHAPE of DM velocity distribution correlates w/ Vc!



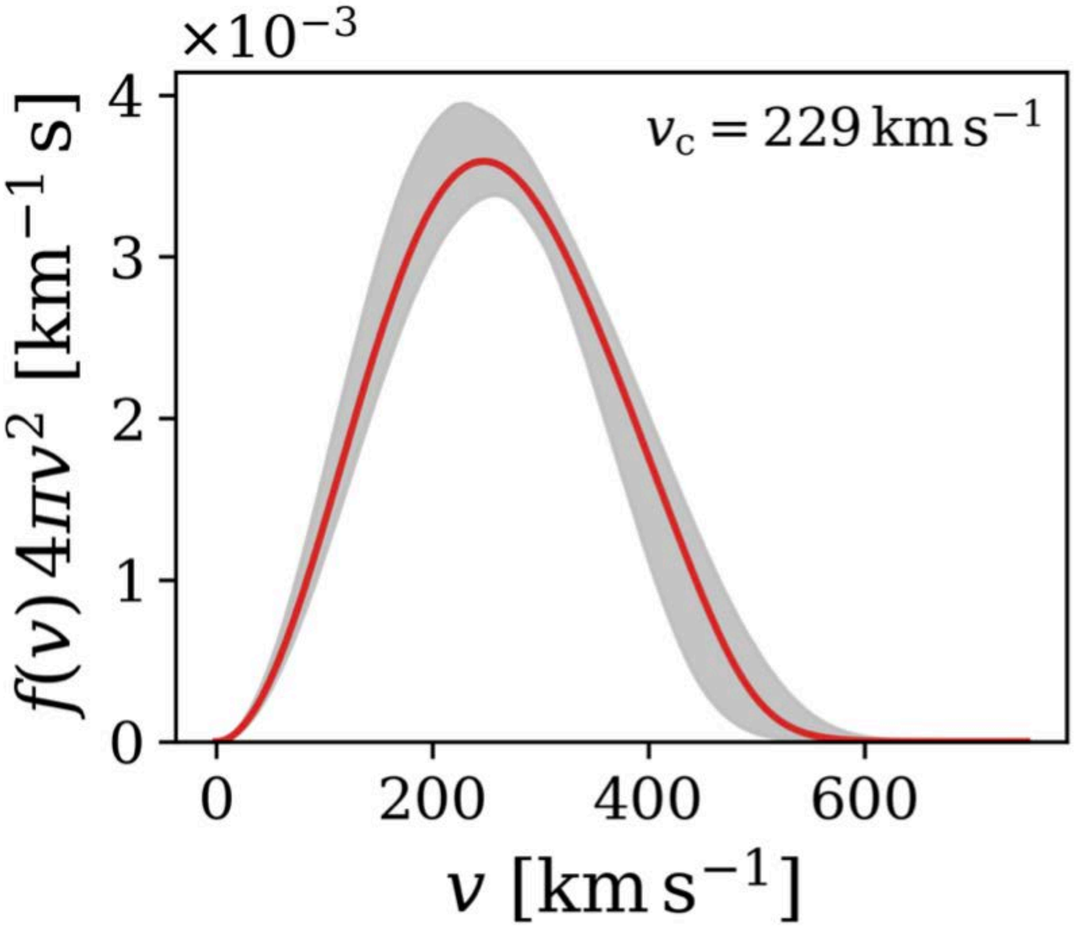
NOT Maxwellian distribution



Maxwellian + damping term

Staudt+23

Predicted DM Velocity Distribution Near Earth



$$f(|\vec{v}|) = \frac{1}{N(v_0, v_{\rm damp})} \exp\left(-\frac{|\vec{v}|^2}{v_0^2}\right) \Theta(v_{\rm damp} - |\vec{v}|),$$

$v_0(v_{\rm c,MW})$	248 ± 19	$\mathrm{km\,s^{-1}}$
$v_{\rm damp}(v_{\rm c,MW})$	490 ± 60	$\mathrm{km\,s^{-1}}$

Staudt+23

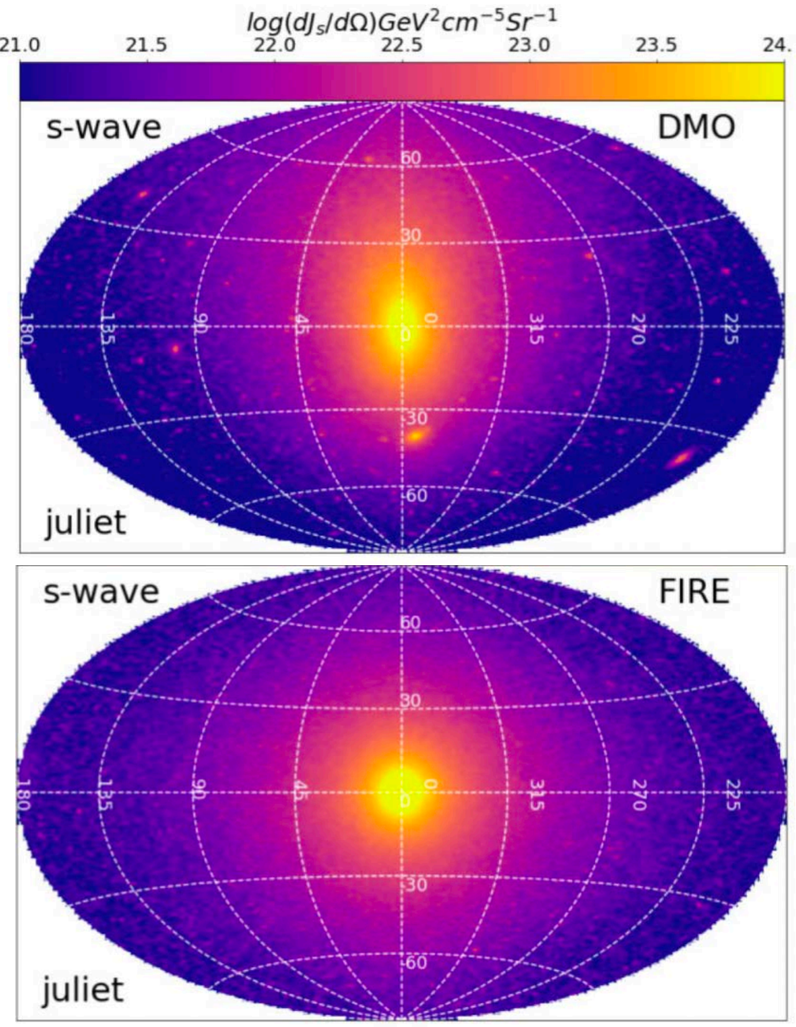
Galaxy formation sims & DM detection

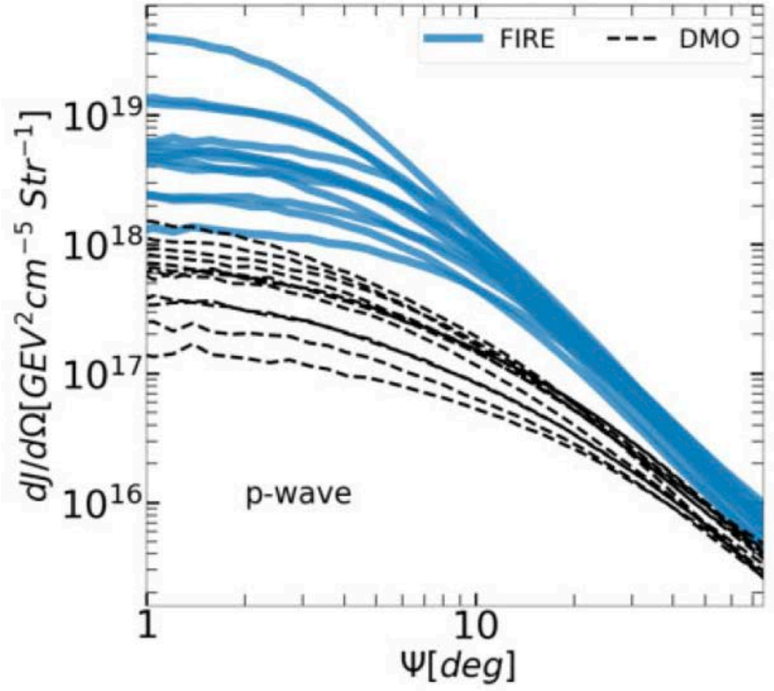
1. Galactic J-factors

Compared to DMO sims:

1) rounder on sky

2) enhanced for p/d-wave





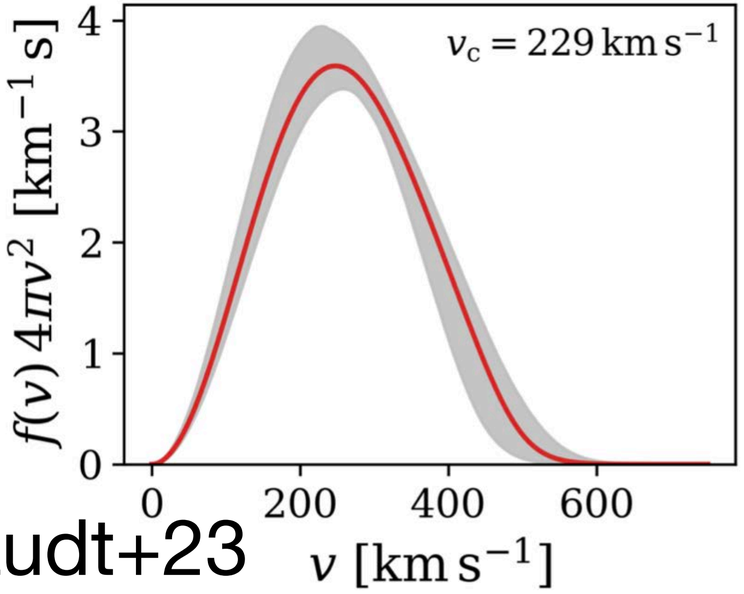
McKeown+22

2. Local DM ρ & σ

Observed Vc allows direct determination of

$$\rho_{\rm DM}(R_\odot) = 0.42 \pm 0.05\,{\rm GeV\,cm^{-3}}$$
$$\sigma_{\rm DM}(R_\odot) = 279 \pm 18\,{\rm km\,s^{-1}}$$

DM speed distribution near Earth



Staudt+23