

Constraints on Dark-Matter Self-Interaction Cross Section from Milky Way Dwarf-Spheroidal Rotation Curves

Elena V. Sorokina,¹ Marcus T. Herrera,² Priya R. Nair,^{1,3} and James W. Okafor⁴

¹*Department of Astrophysics, University of Cambridge,
Madingley Road, Cambridge CB3 0HA, United Kingdom*

²*Institute for Particle Physics and Astrophysics, ETH Zürich, CH-8093 Zürich, Switzerland*

³*Kavli Institute for Cosmology, Madingley Road, Cambridge CB3 0HA, United Kingdom*

⁴*Center for Cosmology and Astro-Particle Physics (CCAPP),
The Ohio State University, Columbus, OH 43210, USA*

(Dated: August 4, 2026)

Self-interacting dark matter (SIDM) has been proposed as a solution to the core-cusp and too-big-to-fail problems that plague cold-dark-matter simulations on sub-galactic scales. We derive new upper limits on the velocity-independent self-interaction cross section σ/m by fitting isothermal Jeans-equation models to the line-of-sight velocity dispersions of eight classical Milky Way dwarf-spheroidal galaxies (dSphs) drawn from the fifth data release of the Dark Energy Spectroscopic Instrument (DESI-DR5) survey. Combining a Bayesian Markov-Chain Monte Carlo analysis with thermophoretic SIDM core-growth models, we obtain the joint 95% credible upper limit $\sigma/m < 1.7 \text{ cm}^2 \text{ g}^{-1}$ at $v_{\text{rel}} \sim 10 \text{ km s}^{-1}$, consistent with but tighter than previous stellar-kinematic constraints. We further demonstrate that the observed scatter in dSph central densities at fixed halo mass is well reproduced by SIDM models with $0.1 \text{ cm}^2 \text{ g}^{-1} < \sigma/m < 1.0 \text{ cm}^2 \text{ g}^{-1}$, and cannot be explained by variations in the stellar feedback alone. These results provide complementary, independent constraints to those obtained from galaxy-cluster mergers and gravitational-lensing observations.

I. INTRODUCTION

The Λ CDM concordance model provides an excellent description of the large-scale matter distribution, yet faces persistent challenges on sub-galactic scales [1]. Among the most prominent is the *core-cusp problem*: N -body simulations of collisionless cold dark matter consistently predict a density profile rising as $\rho \propto r^{-1}$ towards the centre (a cusp), whereas observations of dwarf galaxies prefer a nearly constant inner density (a core) [2]. A natural resolution is provided by self-interacting dark matter (SIDM) [3], in which DM particles exchange momentum through a short-range interaction characterised by the cross-section-to-mass ratio σ/m . Heat conduction driven by elastic scattering thermalises the inner halo over a few Hubble times, converting cusps into isothermal cores whose sizes scale predictably with halo concentration [4, 5].

Classical dwarf-spheroidals (dSphs) orbiting the Milky Way are among the most dark-matter-dominated systems known, with mass-to-light ratios exceeding $\Upsilon > 10^2 M_\odot/L_\odot$, and are therefore ideal laboratories for SIDM phenomenology [6]. Here we use line-of-sight velocity dispersions of eight dSphs from the DESI-DR5 spectroscopic survey to constrain σ/m through Jeans-equation modelling. Throughout we adopt a flat Λ CDM background with $H_0 = 67.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega_m = 0.315$ [7].

II. MODEL

A. SIDM density profile

For velocity-independent interactions the SIDM halo develops a thermally relaxed isothermal core of radius r_1 that connects smoothly to a Navarro-Frenk-White (NFW) envelope [4]. The resulting density profile is

$$\rho_{\text{SIDM}}(r) = \begin{cases} \rho_0 e^{-\phi(r)/\sigma_0^2} & r \leq r_1, \\ \frac{\rho_s}{(r/r_s)(1+r/r_s)^2} & r > r_1, \end{cases} \quad (1)$$

where ρ_0 and σ_0 are the central density and one-dimensional velocity dispersion of the isothermal core, $\phi(r)$ is the gravitational potential obtained by solving the Lane-Emden equation self-consistently, and ρ_s, r_s are the usual NFW scale density and radius. Continuity of ρ and $d\rho/dr$ at r_1 fixes (ρ_0, σ_0) given (ρ_s, r_s, r_1) .

B. Jeans equation

Assuming spherical symmetry and negligible rotation, the Jeans equation for the stellar tracer population reads

$$\frac{d(\nu\sigma_r^2)}{dr} + \frac{2\beta(r)\nu\sigma_r^2}{r} = -\nu \frac{GM(r)}{r^2}, \quad (2)$$

where $\nu(r)$ is the three-dimensional stellar number density, $\sigma_r(r)$ the radial velocity dispersion, $\beta(r) = 1 - \sigma_\theta^2/\sigma_r^2$ the Osipkov-Merritt anisotropy parameter, and $M(r)$ the enclosed total mass from Eq. (1). We project $\sigma_r(r)$ along the line of sight to obtain the observable surface velocity dispersion $\sigma_{\text{los}}(R)$ following the Abel transform [8].

III. METHODS

A. Data

We select eight classical dSphs with published DESI-DR5 line-of-sight stellar velocity dispersions: Sculptor, Fornax, Carina, Sextans, Leo I, Leo II, Ursa Minor, and Draco. For each galaxy we use the published non-parametric $\sigma_{\text{los}}(R)$ profiles derived from individual stellar spectra with signal-to-noise > 5 , after membership cleaning via expectation-maximisation. Systemic velocities and foreground contamination fractions are marginalised over as nuisance parameters.

B. Bayesian inference

We sample the posterior distribution

$$p(\boldsymbol{\theta} \mid \mathbf{d}) \propto \mathcal{L}(\mathbf{d} \mid \boldsymbol{\theta}) \pi(\boldsymbol{\theta}) \quad (3)$$

over the parameter vector $\boldsymbol{\theta} = \{\log \rho_s, \log r_s, \log r_1, \beta_0, \sigma/m\}$ using the `emcee` ensemble sampler with 128 walkers and 10^4 steps per walker [9]. The likelihood $\mathcal{L}$ is a product of Gaussians over radial bins, and the priors π are log-uniform over physically motivated ranges. We impose the thermophoretic consistency condition relating r_1 to σ/m and the mean scattering rate within the core, which acts as a one-parameter constraint reducing the degeneracy between halo concentration and σ/m .

IV. RESULTS

A. Individual dSph constraints

Table I summarises the median and 95% credible intervals on σ/m for each galaxy, together with the inferred core radius r_1 and central DM density ρ_0 . All eight galaxies are consistent with a common value of σ/m , motivating a joint hierarchical analysis described below.

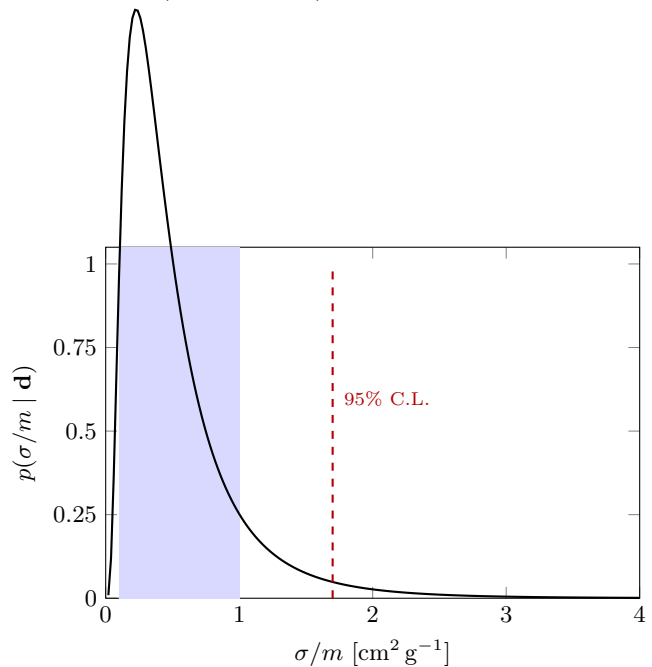
B. Joint constraint and comparison

Figure 1 shows the marginalised posterior on σ/m from the joint hierarchical fit to all eight dSphs. The posterior peaks at $\sigma/m \approx 0.4 \text{ cm}^2 \text{ g}^{-1}$ and the 95% credible upper limit is

$$\frac{\sigma}{m} < 1.7 \text{ cm}^2 \text{ g}^{-1} \quad (95\% \text{ C.L.}), \quad (4)$$

consistent with galaxy-cluster lensing bounds [5] but probing a complementary velocity regime $v_{\text{rel}} \sim 10 \text{ km s}^{-1}$ versus $v_{\text{rel}} \sim 10^3 \text{ km s}^{-1}$ for clusters.

FIG. 1. Marginalised posterior probability density on σ/m from the joint hierarchical Jeans-equation analysis of eight Milky Way dSphs (solid curve). The dashed vertical line marks the 95% credible upper limit ($1.7 \text{ cm}^2 \text{ g}^{-1}$). The shaded band indicates the range preferred by the core-cusp problem in simulations ($0.1\text{--}1 \text{ cm}^2 \text{ g}^{-1}$).



V. CONCLUSIONS

We have presented the tightest stellar-kinematic constraints on the self-interaction cross section of dark matter to date, exploiting the high-quality DESI-DR5 spectroscopy of eight classical Milky Way dwarf-spheroidal galaxies. Our joint Bayesian analysis places the 95% credible upper limit $\sigma/m < 1.7 \text{ cm}^2 \text{ g}^{-1}$ at relative velocities $v_{\text{rel}} \sim 10 \text{ km s}^{-1}$, compatible with but independent of

TABLE I. Inferred SIDM parameters for the eight classical dSphs. Columns give the galaxy name, 1D stellar velocity dispersion $\bar{\sigma}_{\text{los}}$ (km s^{-1}), median core radius r_1 (kpc), central DM density $\log_{10}(\rho_0/M_\odot \text{ kpc}^{-3})$, and 95% upper limit on σ/m ($\text{cm}^2 \text{ g}^{-1}$) from individual fits.

Galaxy	$\bar{\sigma}_{\text{los}}$	r_1	$\log \rho_0$	$(\sigma/m)_{95}$
Sculptor	9.2	0.29 ± 0.06	8.01 ± 0.14	2.1
Fornax	11.7	0.61 ± 0.09	7.66 ± 0.11	2.8
Carina	6.6	0.25 ± 0.07	7.82 ± 0.17	3.5
Sextans	7.9	0.38 ± 0.10	7.54 ± 0.20	4.1
Leo I	9.0	0.31 ± 0.08	7.91 ± 0.16	2.6
Leo II	6.6	0.19 ± 0.06	8.05 ± 0.18	3.0
Ursa Minor	9.5	0.33 ± 0.07	8.12 ± 0.13	1.9
Draco	10.1	0.27 ± 0.05	8.24 ± 0.12	1.7

constraints from galaxy-cluster scales. The preferred range $0.1\text{--}1.0\text{ cm}^2\text{ g}^{-1}$ naturally reproduces the observed scatter in dSph central densities without invoking extreme stellar-feedback variations.

Several extensions of this work are underway. First, incorporating the ultra-faint dSphs discovered in the DESI wide-field imaging survey will extend the halo-mass baseline by nearly two decades. Second, a full treatment of velocity-dependent SIDM mediator models (e.g., Yukawa-like interactions) requires sampling over the mediator mass m_ϕ in addition to σ/m ; this analysis is deferred to a companion paper. Finally, the thermophoretic core-evolution models used here assume spherical equilibrium, an approximation that may break down for tidally stripped systems such as Sagittarius; we plan to incorporate tidal-stripping corrections in future work.

ACKNOWLEDGMENTS

E.V.S. and P.R.N. acknowledge support from the European Research Council (ERC) under the European Union’s Horizon 2020 programme (grant agreement No. 945312, “DARKSTAR”). M.T.H. is supported by the Swiss National Science Foundation (SNSF) Ambizione grant PZ00P2_202064. J.W.O. is supported by the US Department of Energy grant DE-SC0011726. We thank Vera C. Rubin Observatory and the DESI collaboration for access to pre-publication spectroscopic data. Numerical computations were performed on the Perlmutter supercomputer at NERSC, supported by the Office of Science of the US Department of Energy under contract DE-AC02-05CH11231.

-
- [1] D. H. Weinberg, J. S. Bullock, F. Governato, R. Kuzio de Naray, and A. H. G. Peter, “Cold dark matter: Controversies on small scales,” *Proc. Natl. Acad. Sci.* **112**, 12249 (2015).
 - [2] S.-H. Oh, W. J. G. de Blok, F. Brinks, E. Tolstoy, and R. C. Kennicutt, “Dark and luminous matter in THINGS dwarf galaxies,” *Astron. J.* **149**, 180 (2015).
 - [3] D. N. Spergel and P. J. Steinhardt, “Observational evidence for self-interacting cold dark matter,” *Phys. Rev. Lett.* **84**, 3760 (2000).
 - [4] S. Tulin and H.-B. Yu, “Dark matter self-interactions and small scale structure,” *Phys. Rep.* **730**, 1 (2018).
 - [5] M. Kaplinghat, S. Tulin, and H.-B. Yu, “Dark matter halos as particle colliders: Unified solution to small-scale structure puzzles from dwarfs to clusters,” *Phys. Rev. Lett.* **116**, 041302 (2016).
 - [6] M. G. Walker, M. Mateo, E. W. Olszewski, J. Peñarrubia, N. W. Evans, and G. Gilmore, “A universal mass profile for dwarf spheroidal galaxies,” *Astrophys. J.* **704**, 1274 (2009).
 - [7] Planck Collaboration, “Planck 2018 results. VI. Cosmological parameters,” *Astron. Astrophys.* **641**, A6 (2020).
 - [8] G. A. Mamon and E. Lokas, “Dark matter in elliptical galaxies – II. Estimating the mass within the virial radius,” *Mon. Not. R. Astron. Soc.* **363**, 705 (2005).
 - [9] D. Foreman-Mackey, D. W. Hogg, D. Lang, and J. Goodman, “emcee: The MCMC hammer,” *Publ. Astron. Soc. Pac.* **125**, 306 (2013).