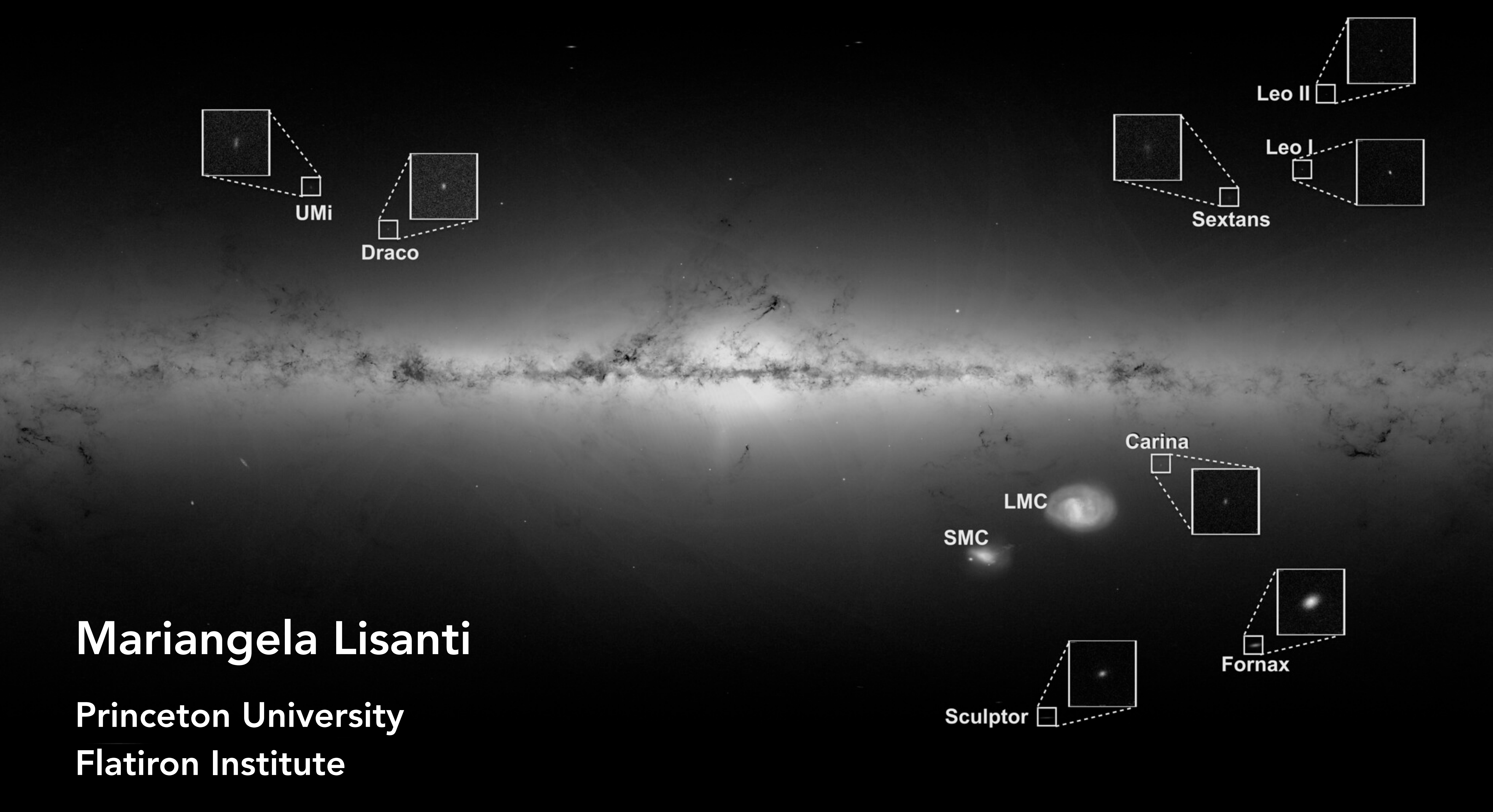
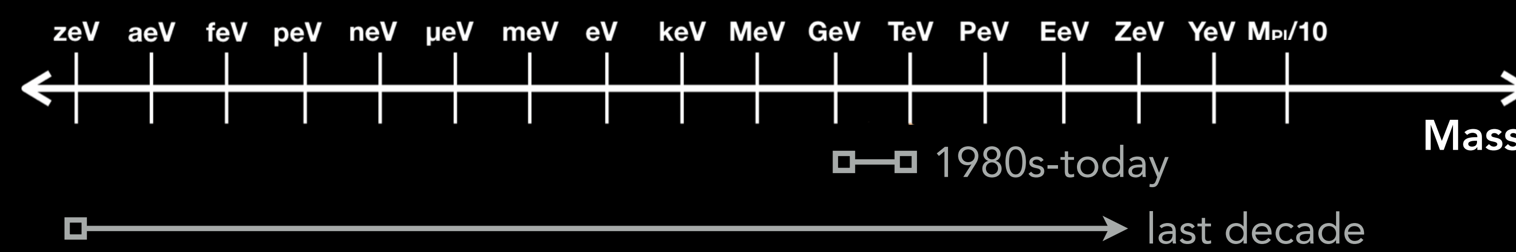
Galaxies as Probes of the Particle Physics Nature of Dark Matter



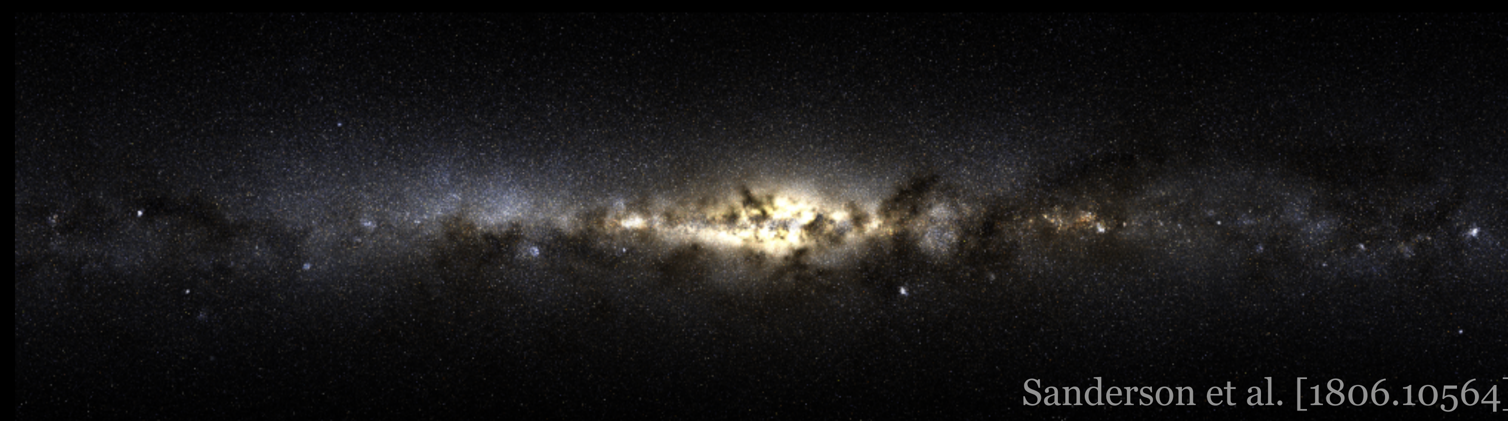
Mariangela Lisanti

Princeton University
Flatiron Institute

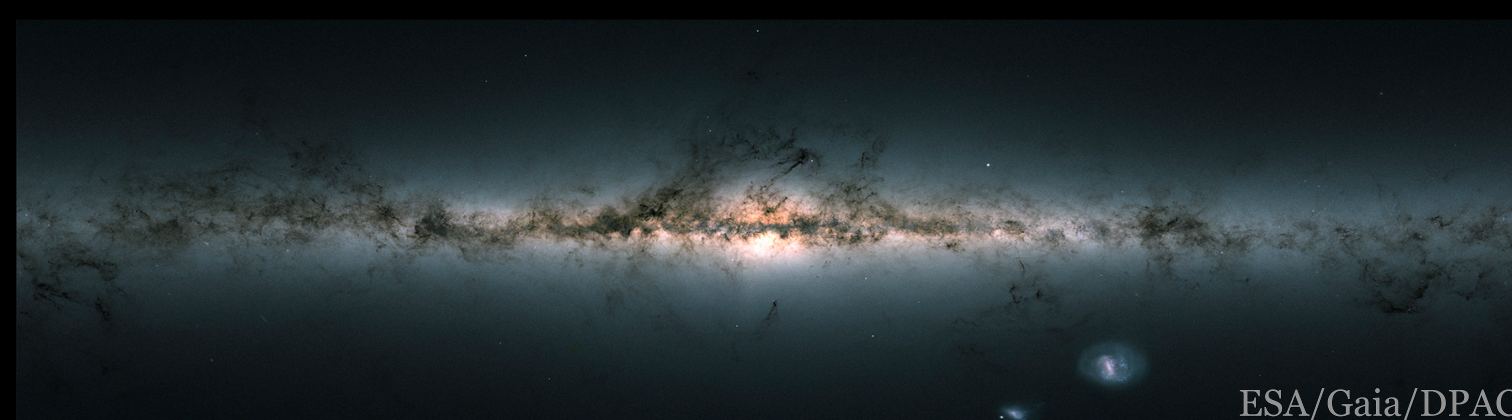
Dark Matter Models



Numerical Simulations


Sanderson et al. [1806.10564]

Wealth of Data


ESA/Gaia/DPAC

Outline

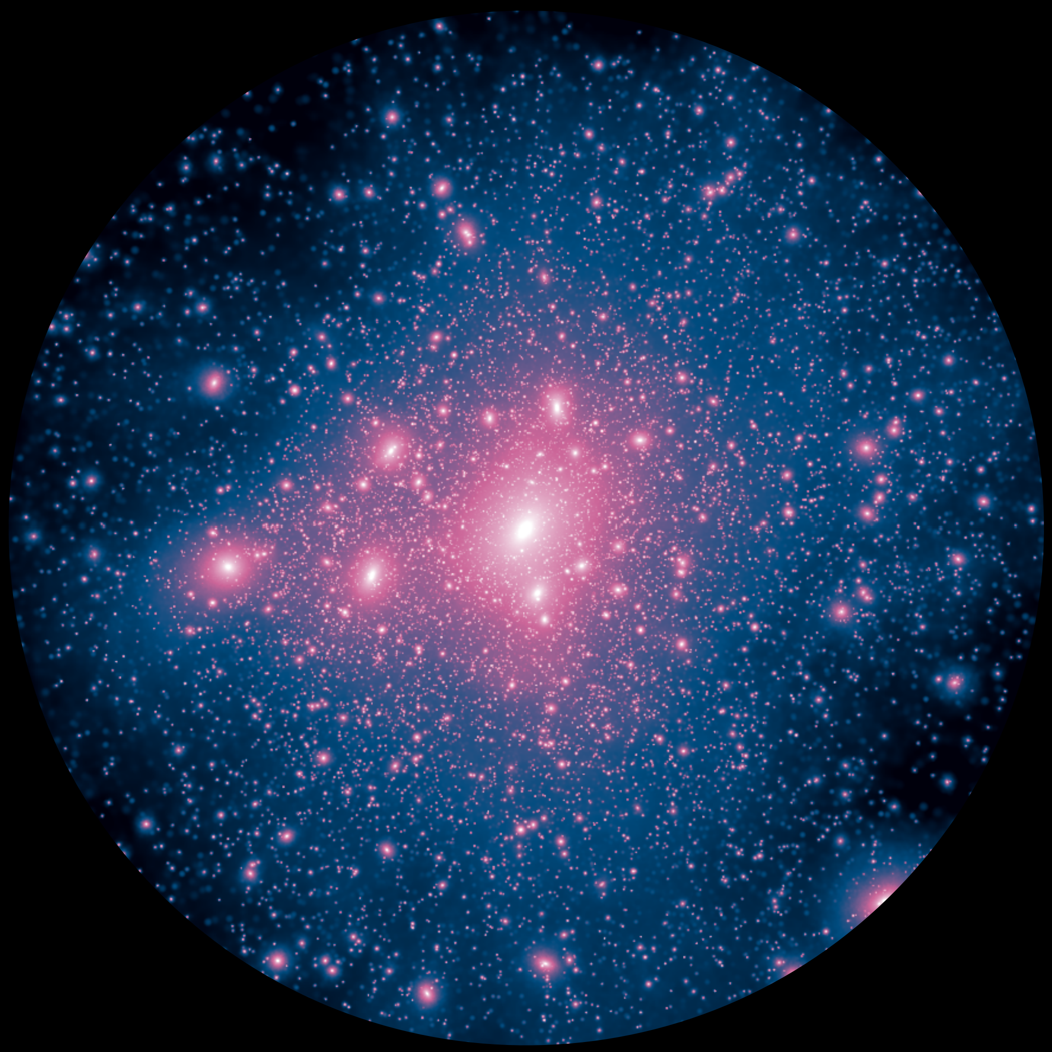
Galaxy Dynamics and Cold Dark Matter

Modeling Challenges

Beyond Cold Dark Matter

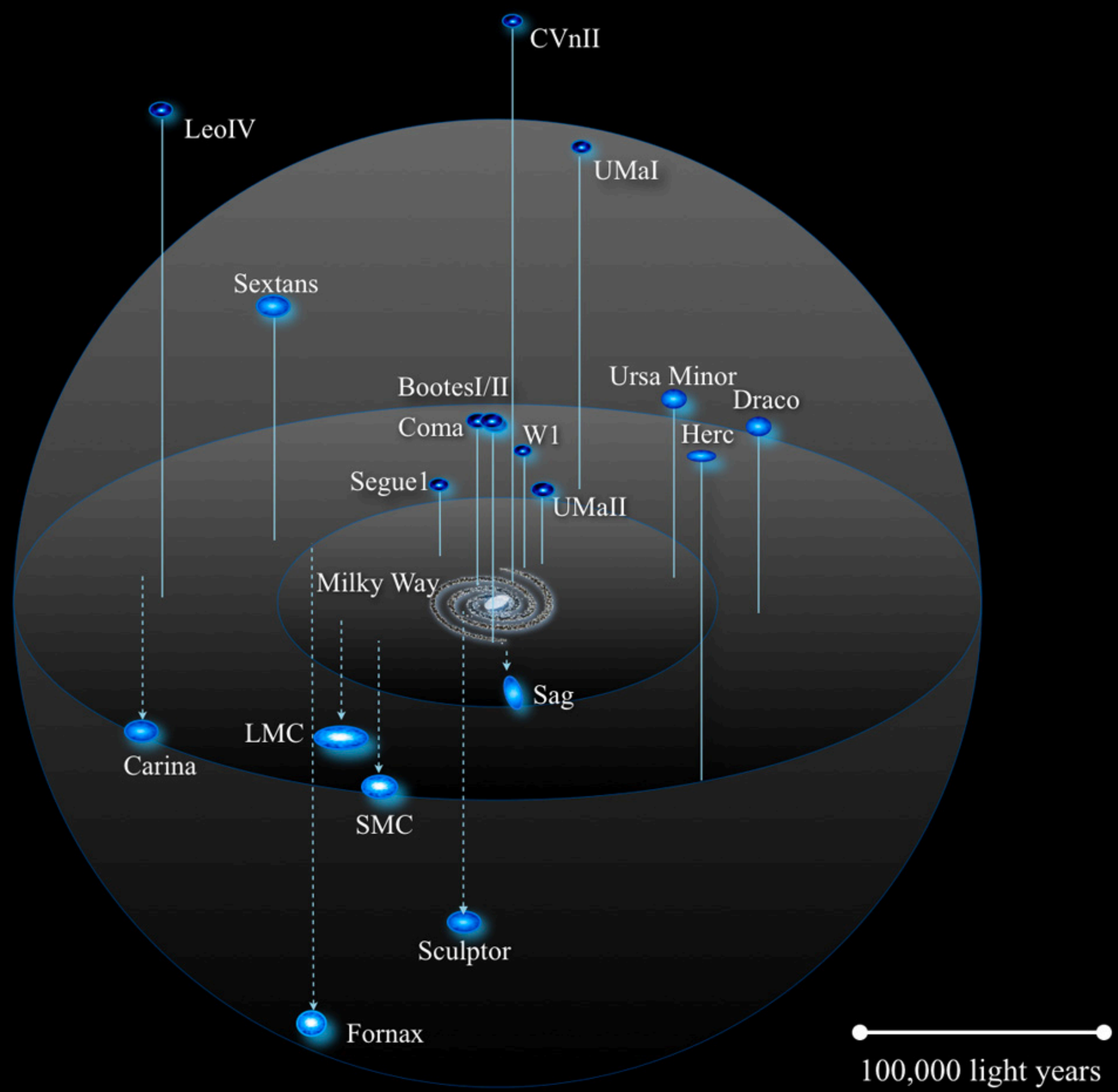
Small-Scale Structure

Dark Matter Halo & Subhalos



Vogelsberger et al. [1512.05349]

Milky Way Dwarf Galaxies

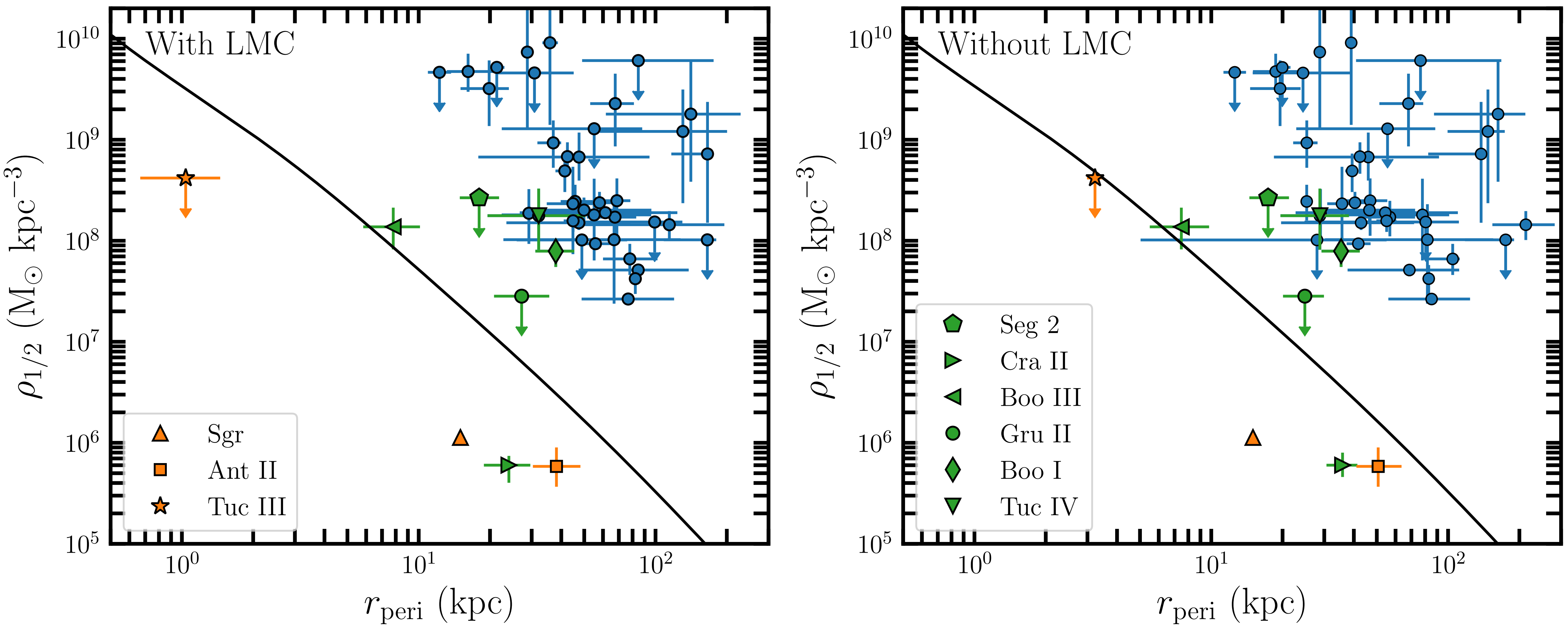


Credit: J. Bullock, M. Geha, R. Powell

Dwarfs in the Milky Way

What are their masses and concentrations?

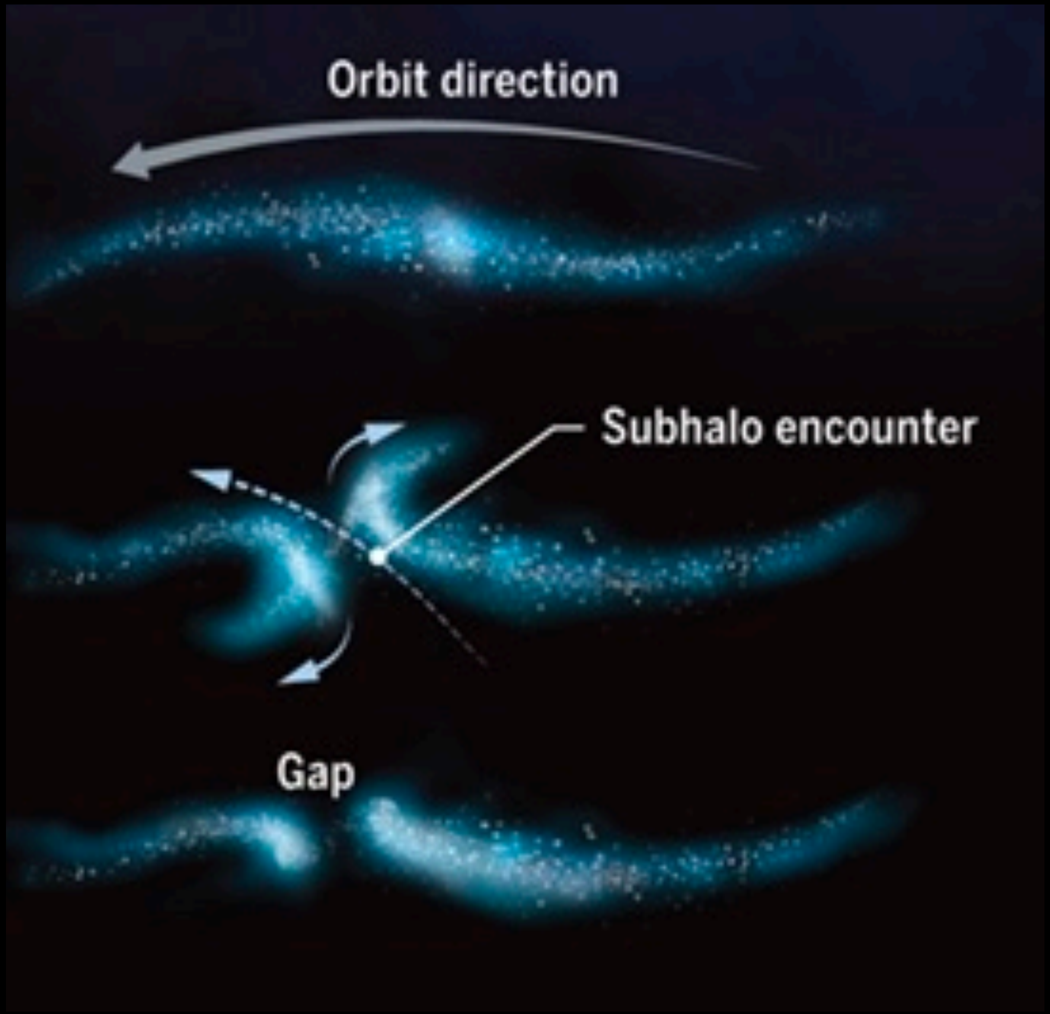
How are they distributed spatially? What are their orbits?



Pace, Erkal, and Li [2205.05699]

Dark Substructure in the Milky Way

Dark subhalos can perturb stellar streams



Credit: C. Bickel/SCIENCE

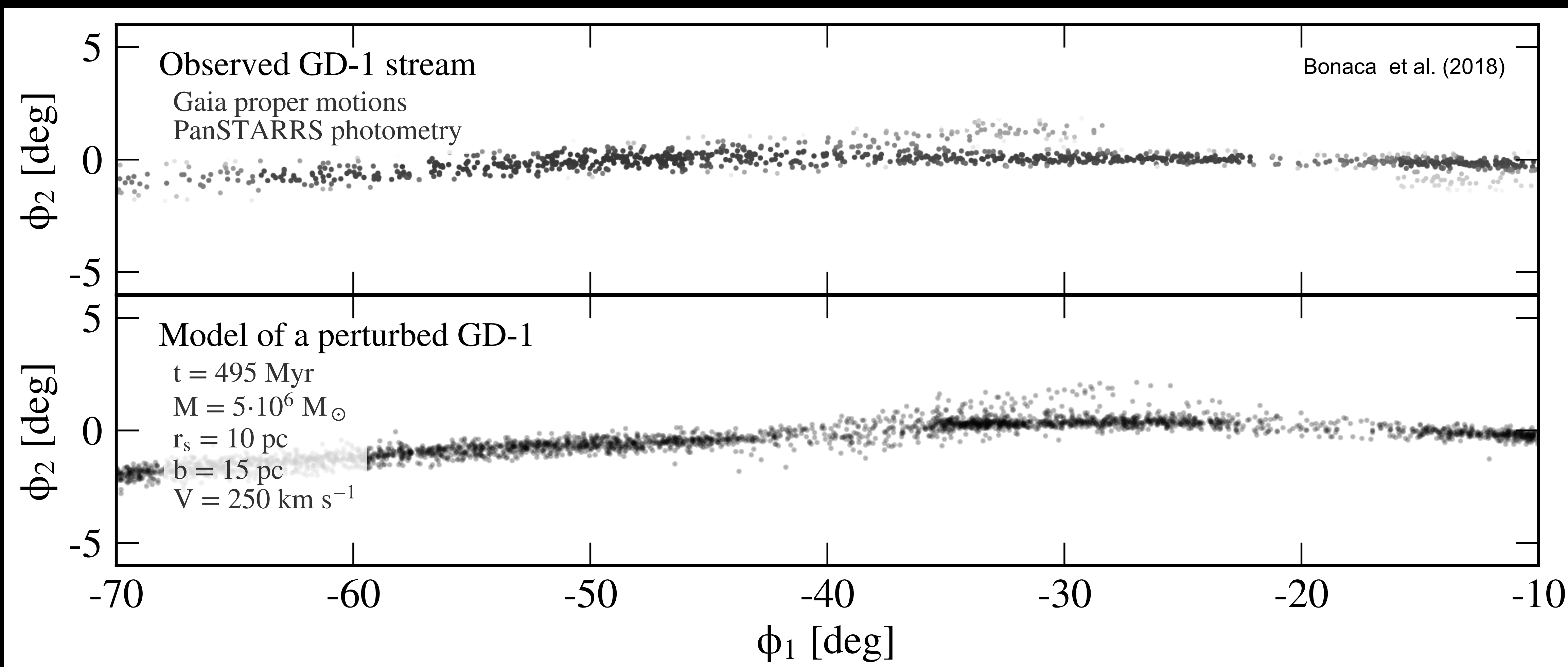
In some cases a subhalo can actually break the stream by flying through it

e.g., Ngan and Carlberg [1311.1710]; Erkal et al. [1606.04946]

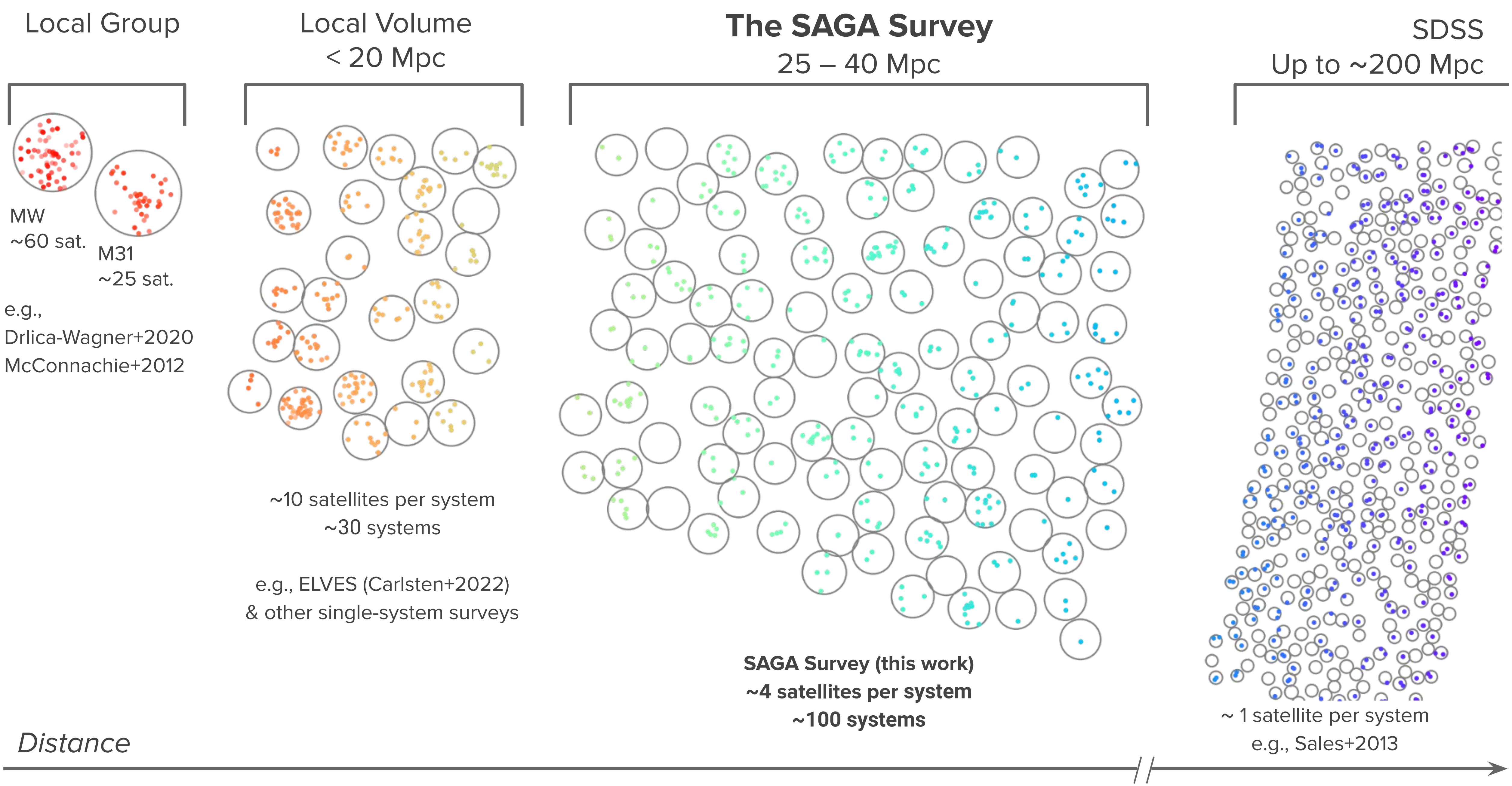
The GD-1 Stream

Do perturbations in GD-1 provide first evidence of a dark matter subhalo in Milky Way?

Price-Whelan & Bonaca [1805.00425]; Bonaca et al. [1811.03631]



Beyond the Milky Way



Mao et al. (SAGA Collaboration) [2404.14498]

Outline

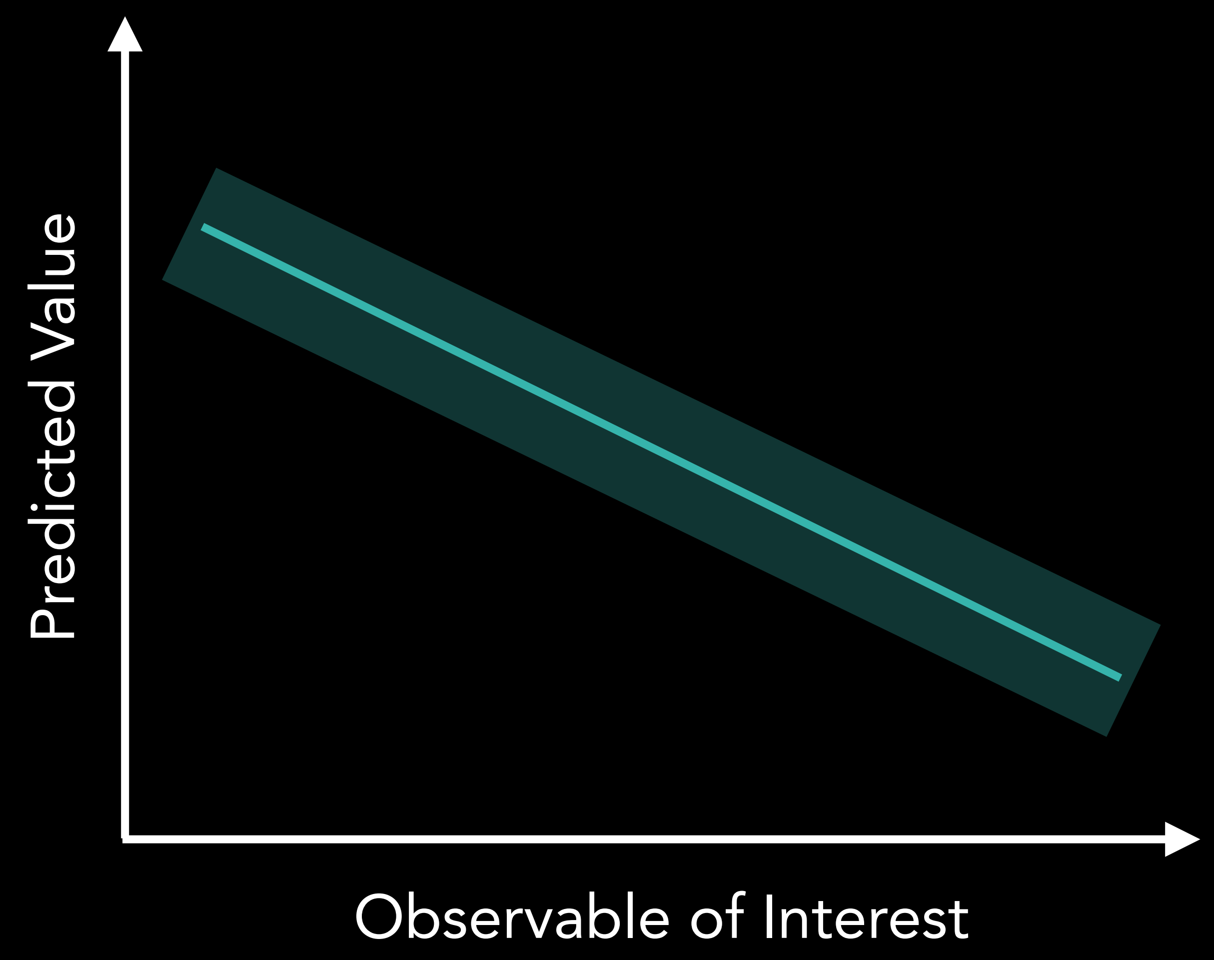
Galaxy Dynamics and Cold Dark Matter

Modeling Challenges

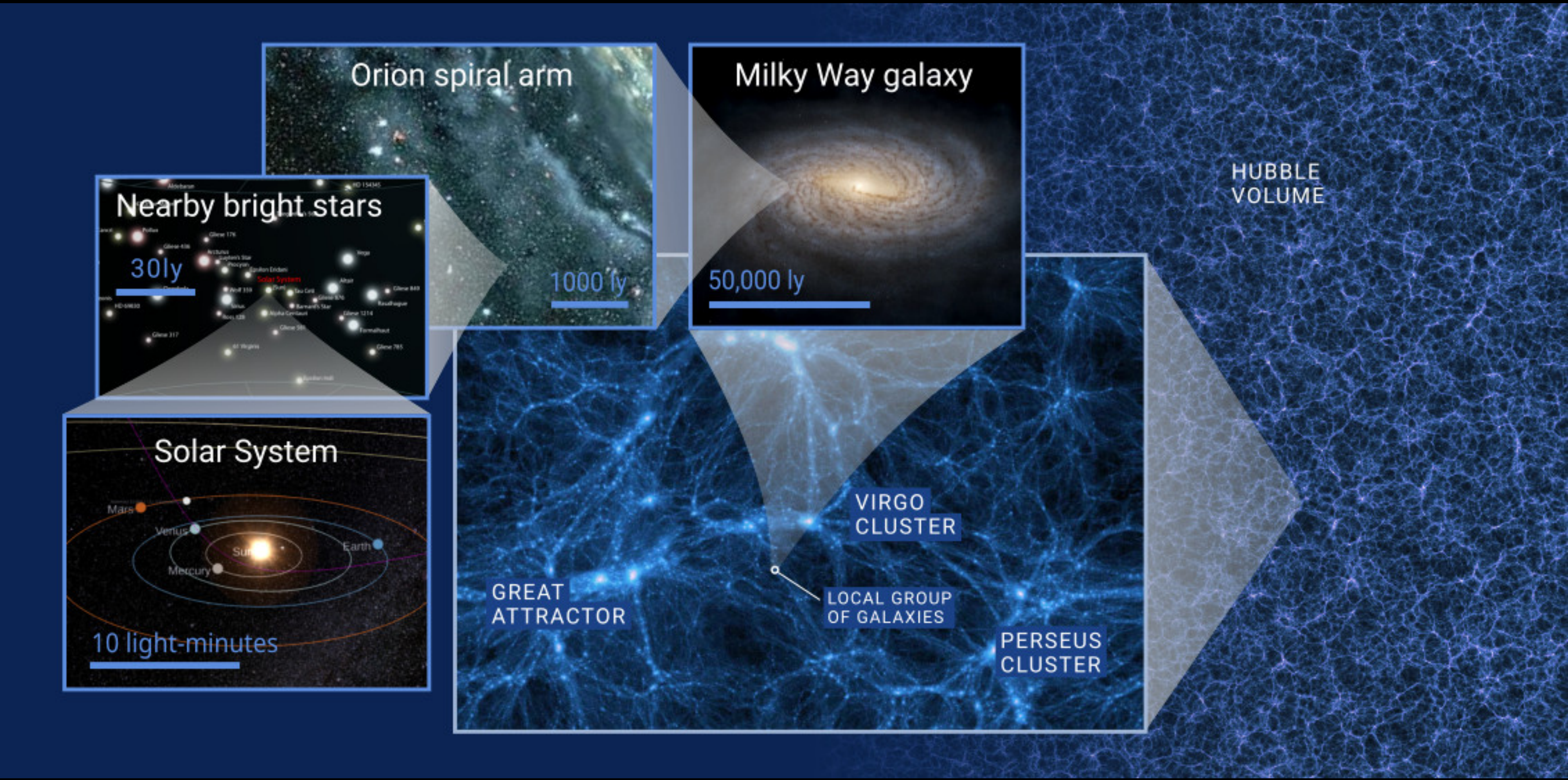
Beyond Cold Dark Matter

Goal for CDM

Obtain robust theory predictions for sub-galactic observables with *well-quantified* uncertainties



Challenge #1: Halo-to-Halo Variance



Credit: https://structures.uni-heidelberg.de/blog/posts/2022_12_cw/
adaptions of images of NASA, theskylive.com, GAIA and the CLUES project

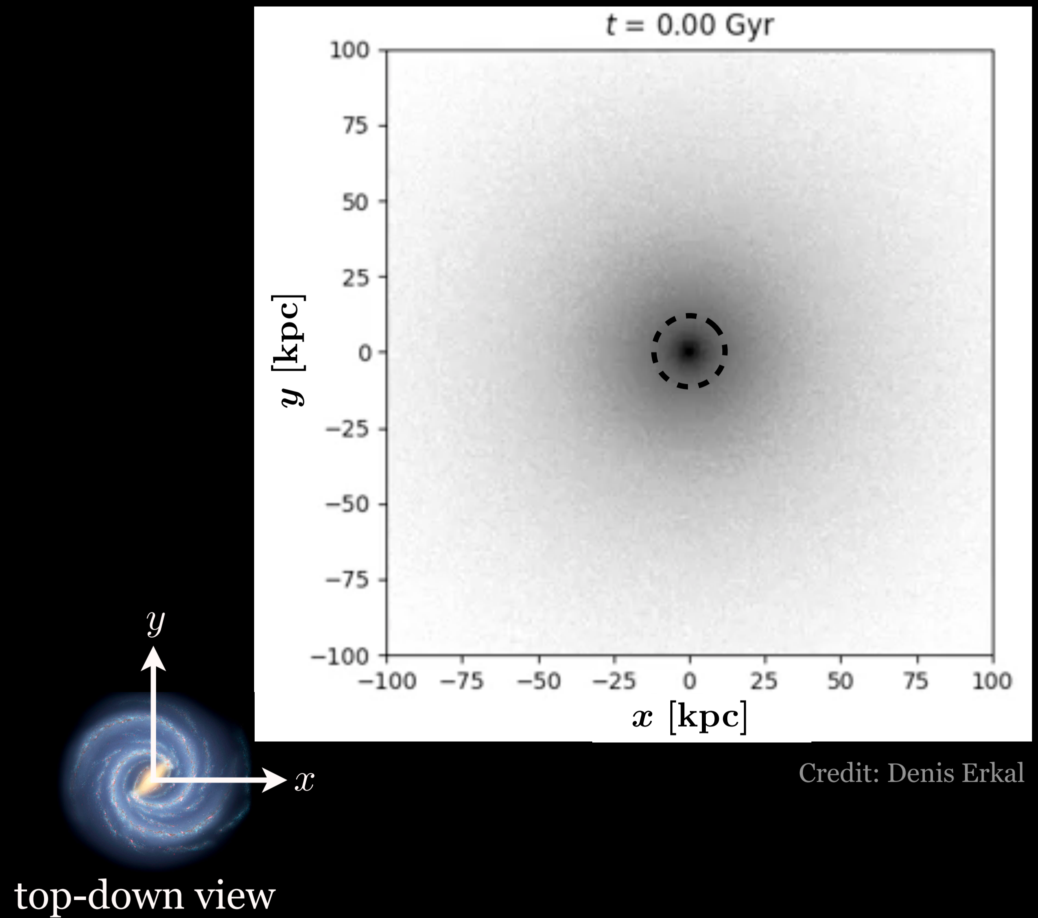
Challenge #1: Halo-to-Halo Variance

Milky Way appears to be defined by two key events in its history

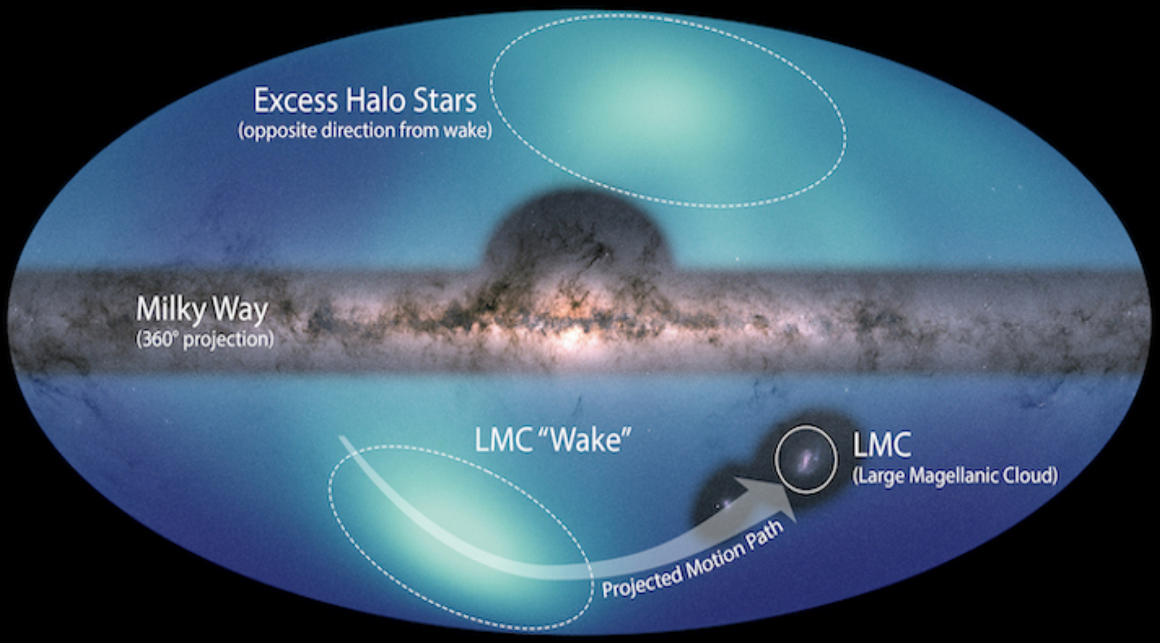
Gaia Sausage Enceladus (GSE)

Large Magellanic Cloud (LMC)

Gray: Milky Way stars   Red: Merger stars



Credit: Denis Erkal



Credit: https://osr.org/blog/news/large-magellanic-cloud-wake-reveals-dark-matter/


Dylan Folsom

Challenge #1: Halo-to-Halo Variance

An IllustrisTNG (50 Mpc)^3 volume contains ~100 isolated Milky Way-mass halos of which:

~30 have had a GSE-like event(s)

~2 have had a GSE *and* LMC-like event

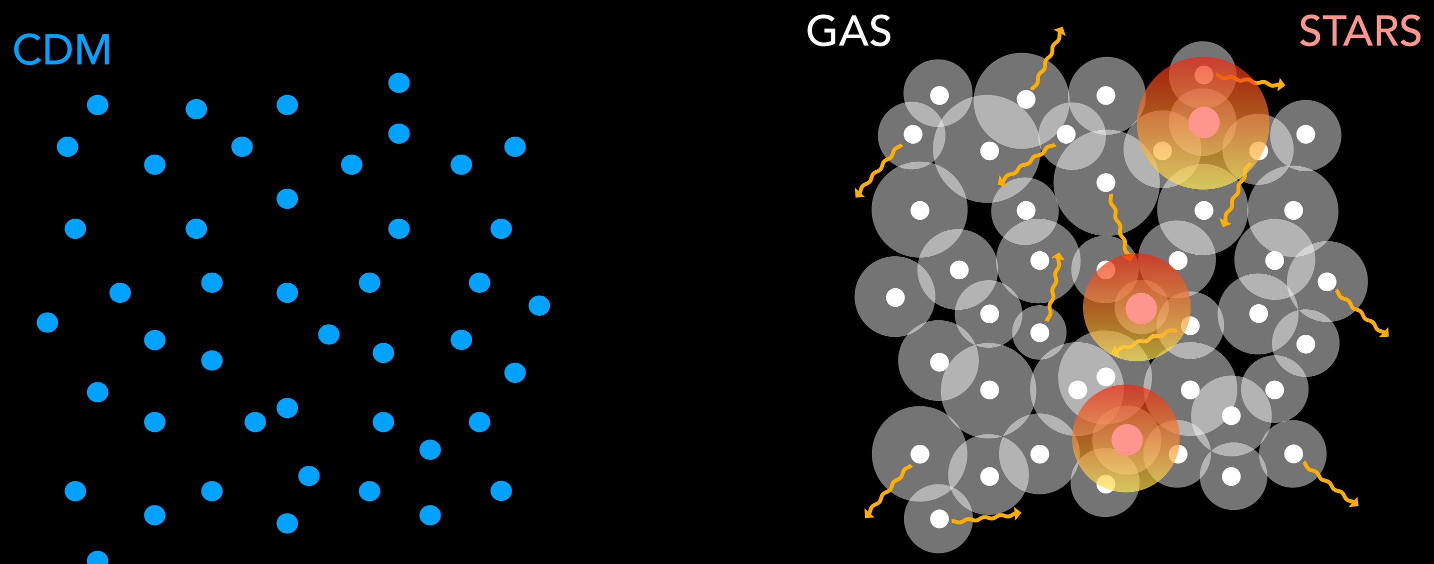
D. Folsom, **ML**, L. Necib, D. Horta, M. Vogelsberger, and L. Hernquist [2408.02723]

We are Rare

See also Buch et al. [2404.08043]

Challenge #2: Baryonic Physics

A Primer to Hydro Codes

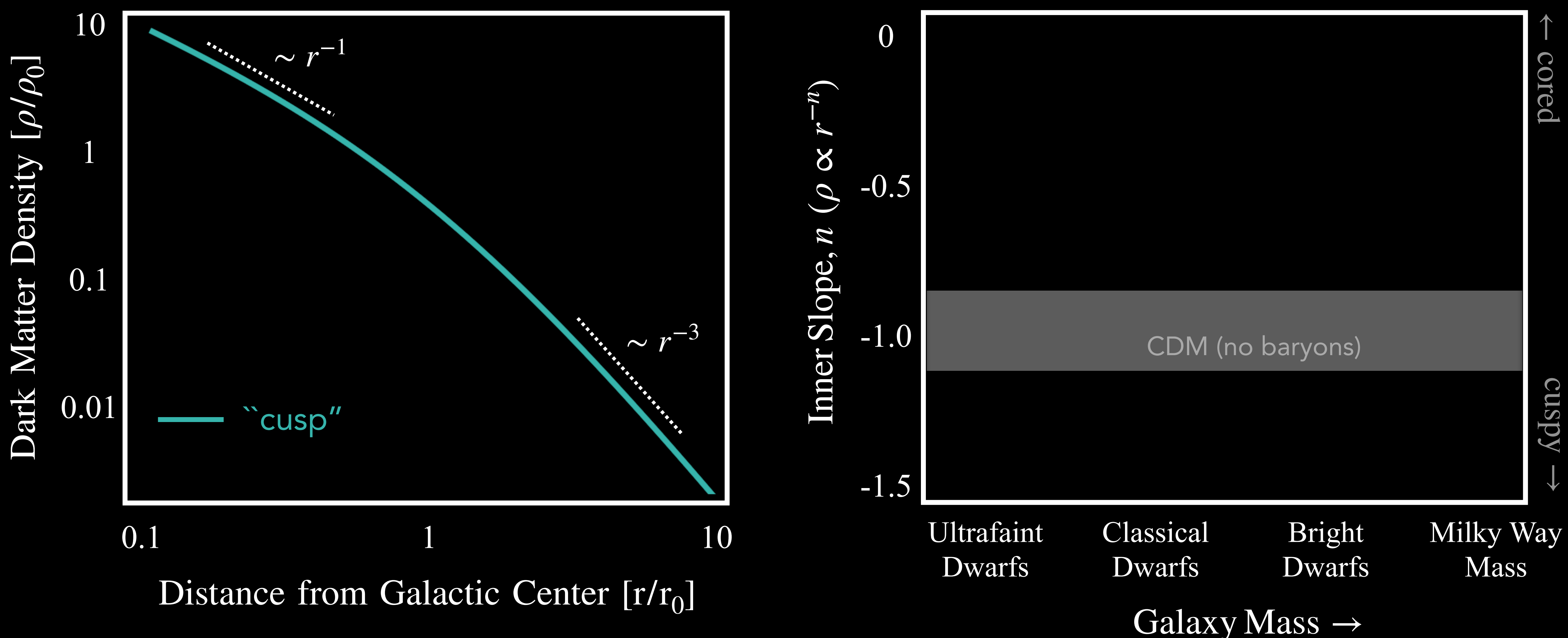


Credit: Sandip Roy

Supernova explosions redistribute baryons and dark matter in galaxies

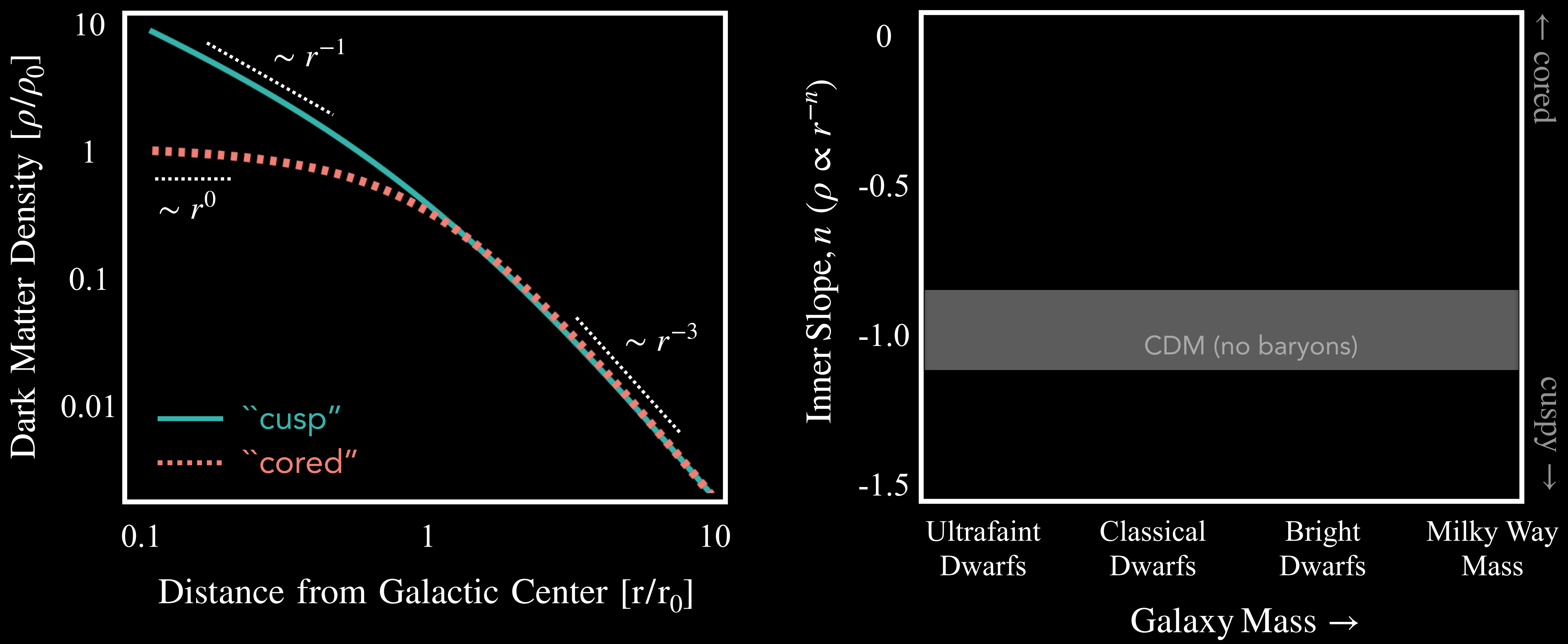
Remains a significant source of uncertainty in galaxy simulations

Challenge #2: Baryonic Physics



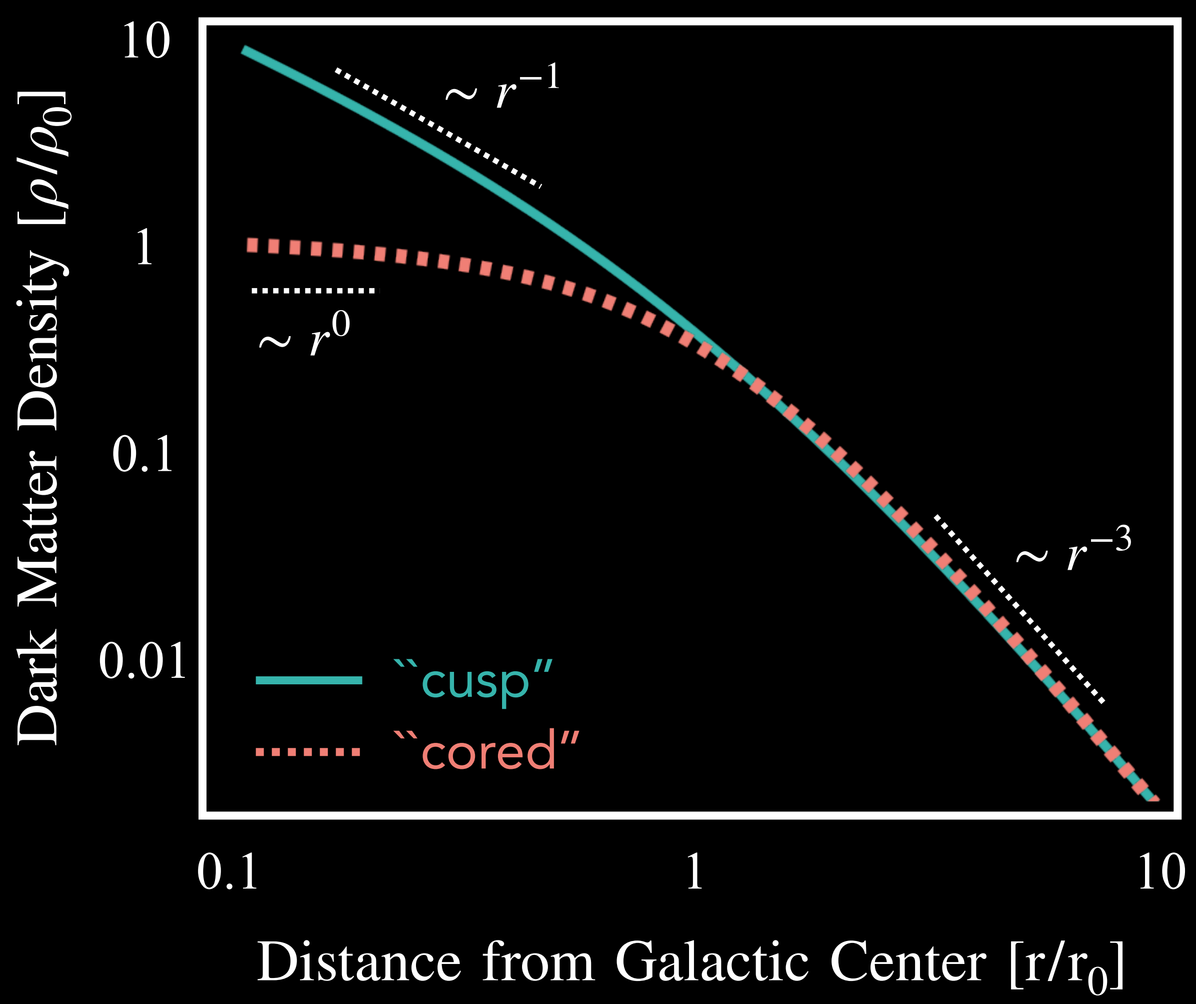
Challenge #2: Baryonic Physics

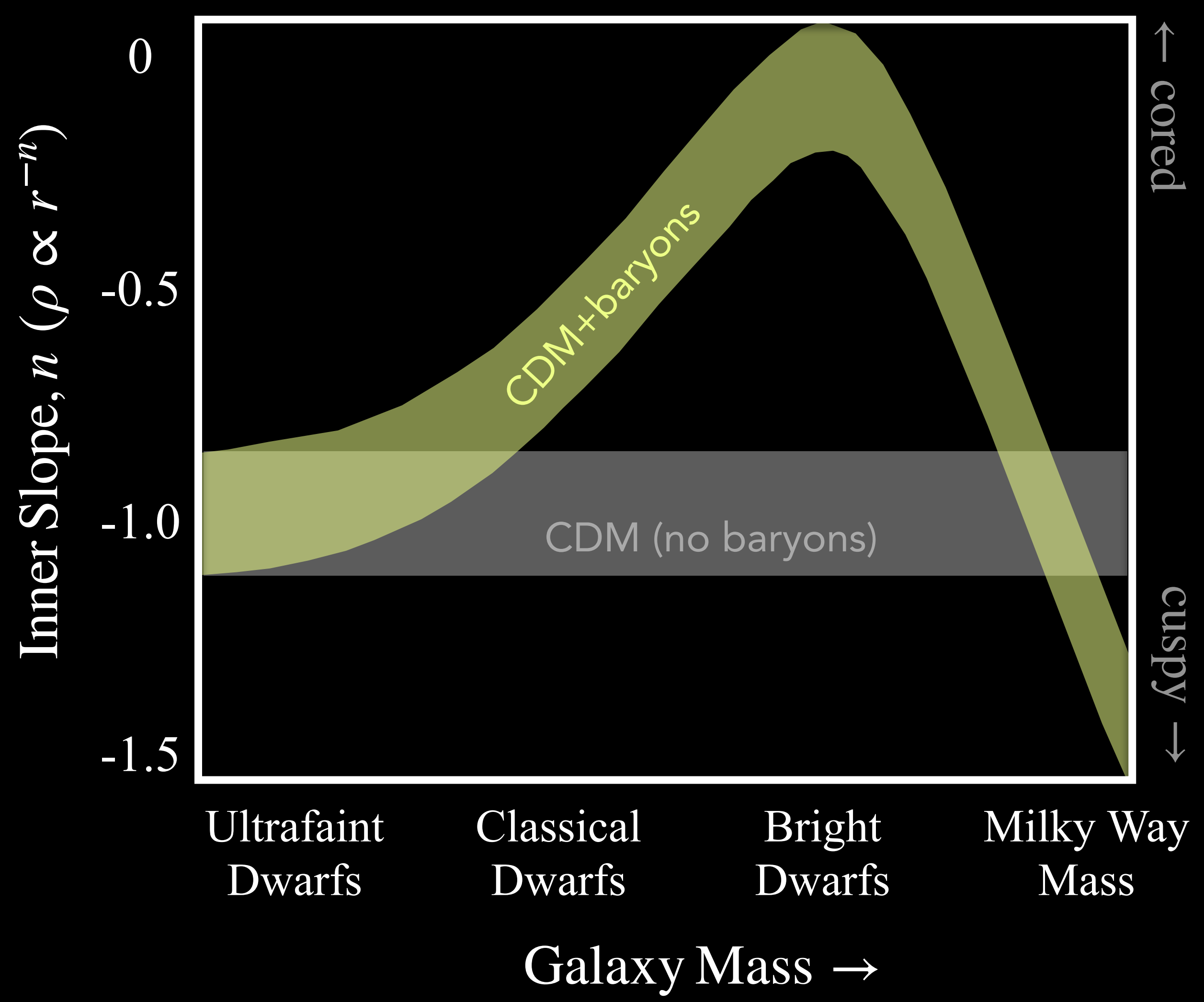
Energy injection from stellar feedback processes can `core' the inner-most regions of CDM halos



Challenge #2: Baryonic Physics

Energy injection from stellar feedback processes can `core' the inner-most regions of CDM halos





Jonah Rose

The DREAMS Project

J. Rose, P. Torrey, F. Villaescusa-Navarro, **ML**, et al. [2405.00766]

Producing the largest-ever hydro simulation suites that vary over astro and particle physics uncertainties

Suites will be created for different targets (Milky Way, dwarf, …) and different dark matter models

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Galaxy Dynamics and Cold Dark Matter

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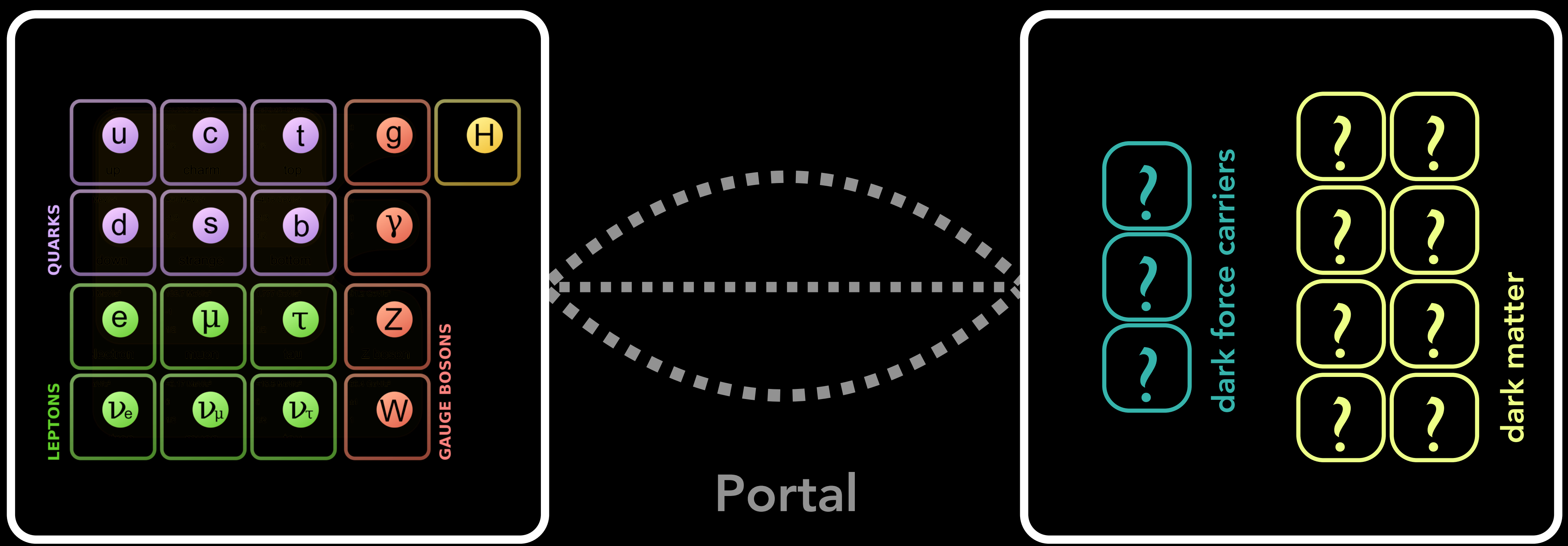
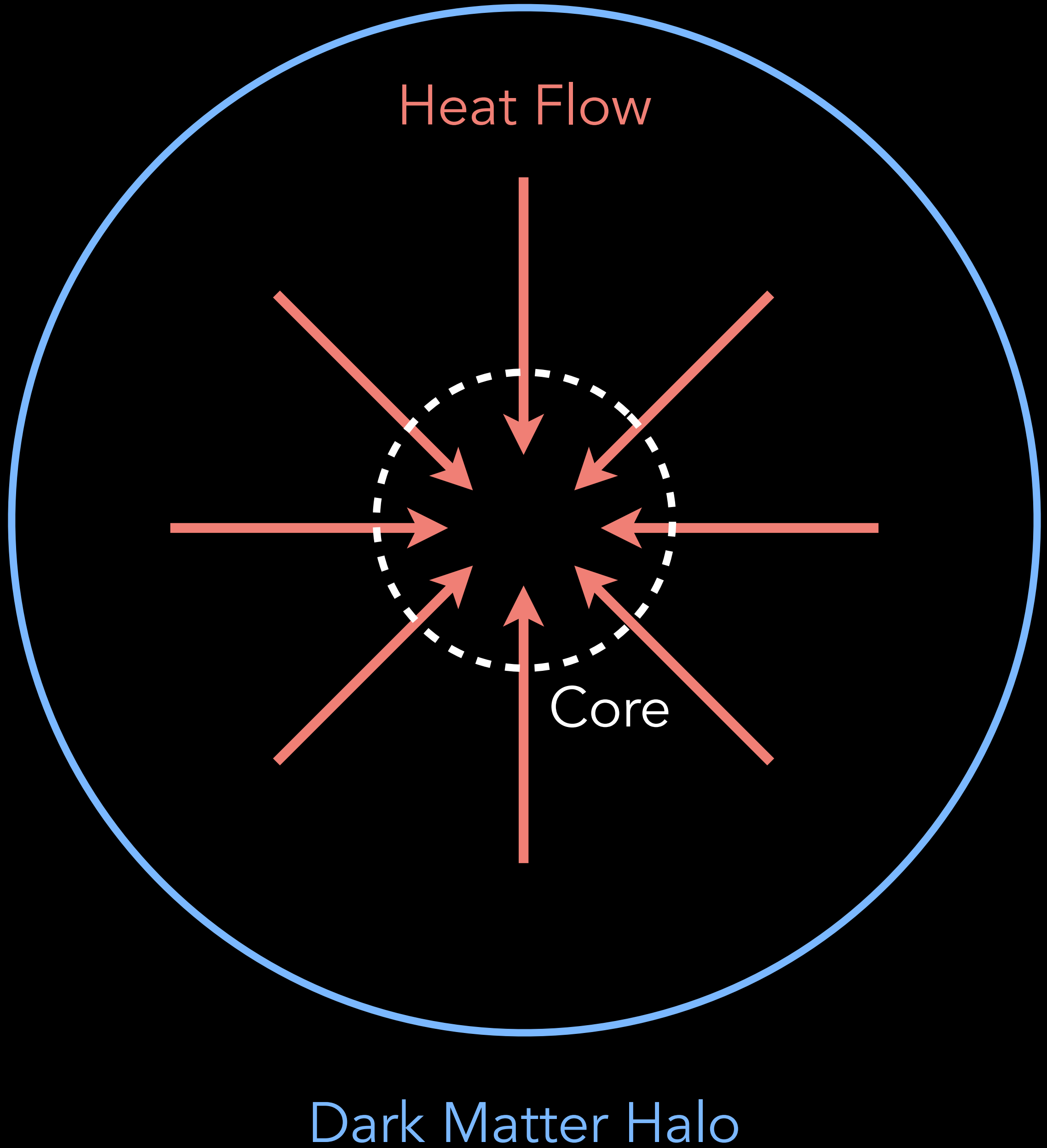
Theory of Dark Sectors



What if new forces allow dark matter to interact with itself either elastically or inelastically?

Elastic Self Interactions

Self interactions enable heat flow in a halo, redistributing dark matter



Stage 1: Isothermal Core Formation

Heat flows *inwards*

Vogelsberger et al. [1201.5892]; Zavala et al. [1211.6426]; Robles et al. [1903.01469]; Zavala et al. [1904.09998]

Elastic Self Interactions

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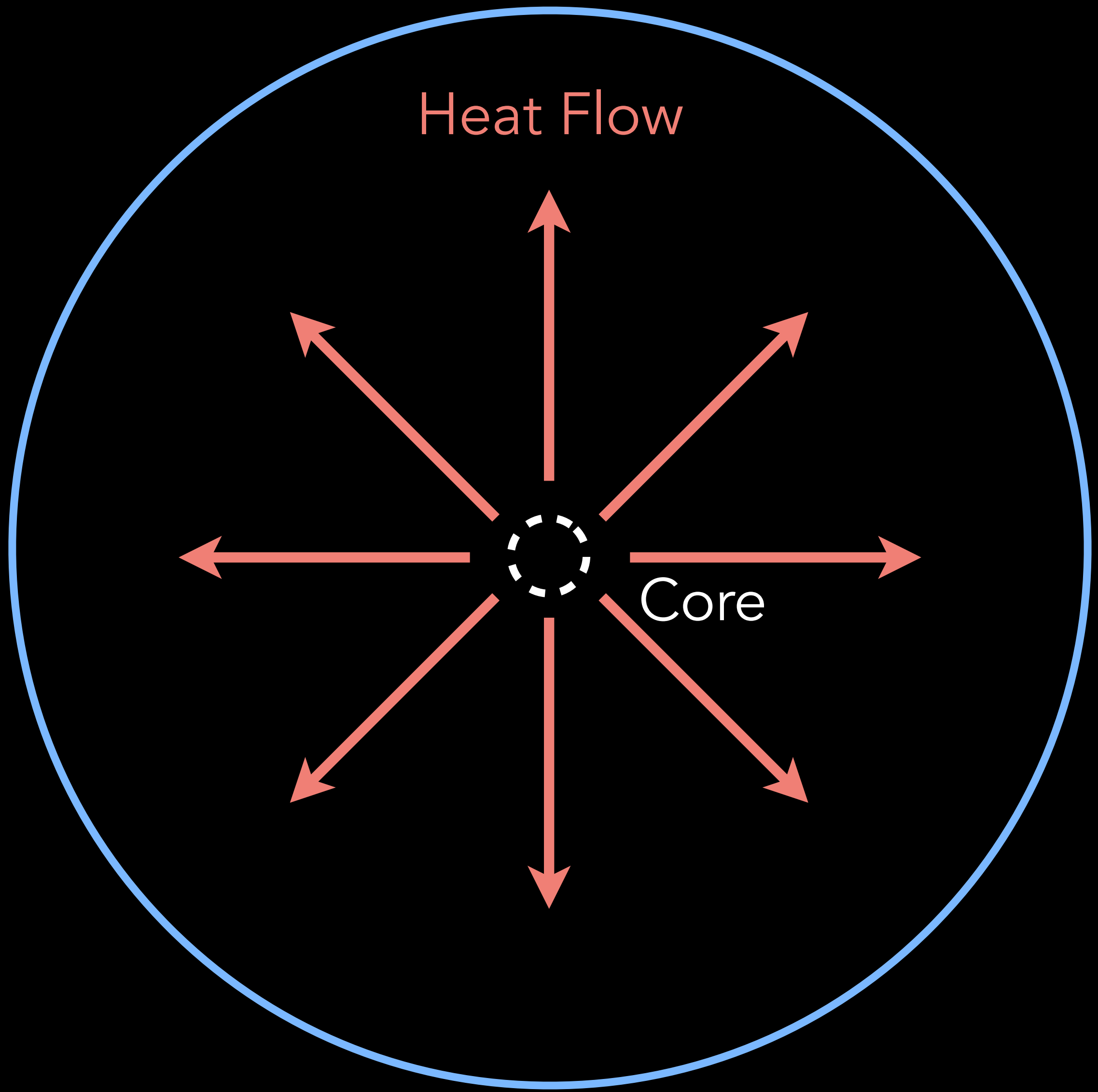


Stage 1: Isothermal Core Formation

Heat flows *inwards*

Stage 2: Core Collapse

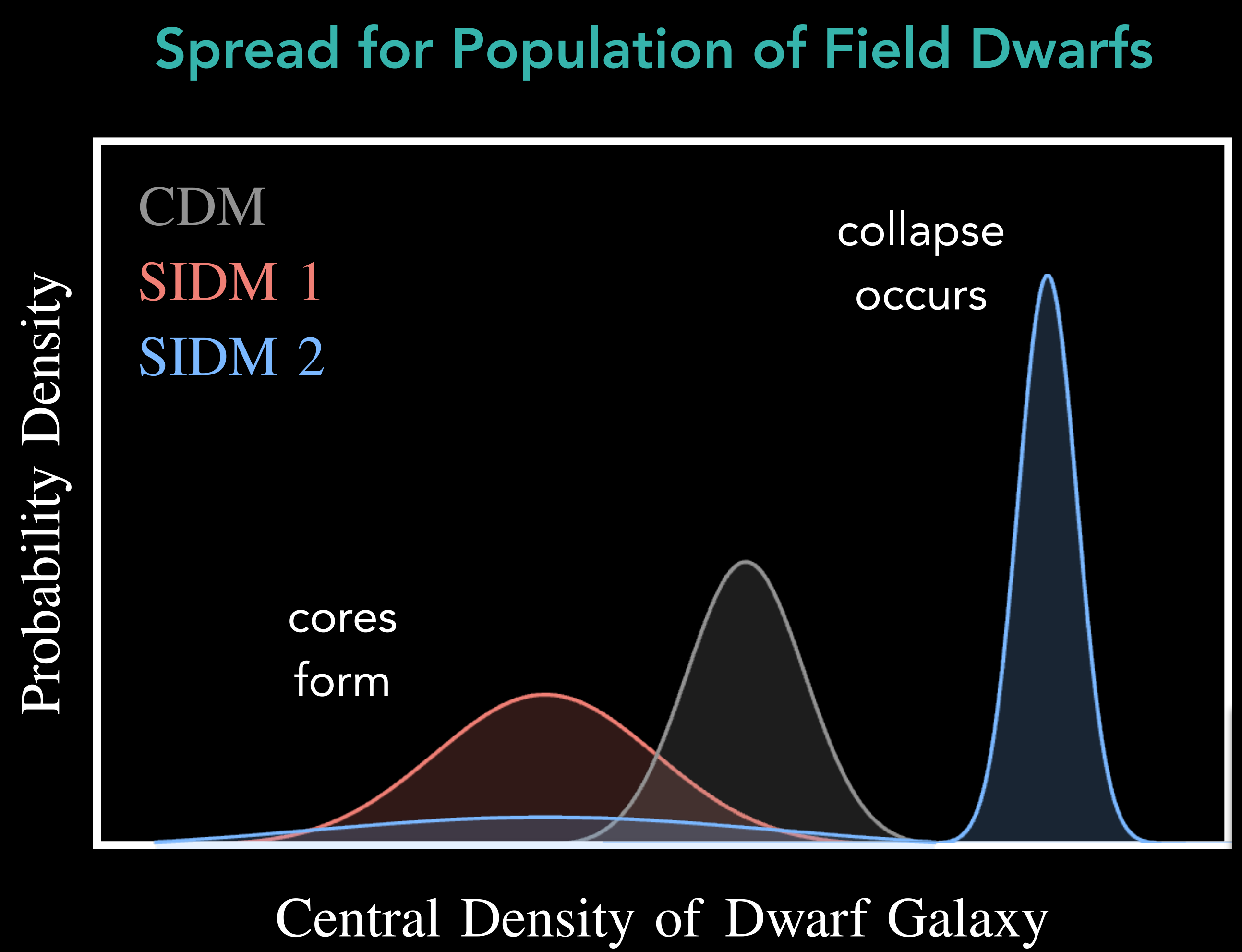
Heat flows *outwards*

Balberg et al. [astro-ph/0110561]; Koda and Shapiro [1101.3097]; Elbert et al. [1412.1477];
Essig et al. [1809.01144]; Nishikawa et al. [1901.0049]; Kahlhoefer et al. [1904.10539]; Turner et al. [2010.02924]

Oren Slone

Dwarf Population Statistics

Gravothermal collapse can lead to a mixture of cores and dense cusps across a population of dwarf galaxies



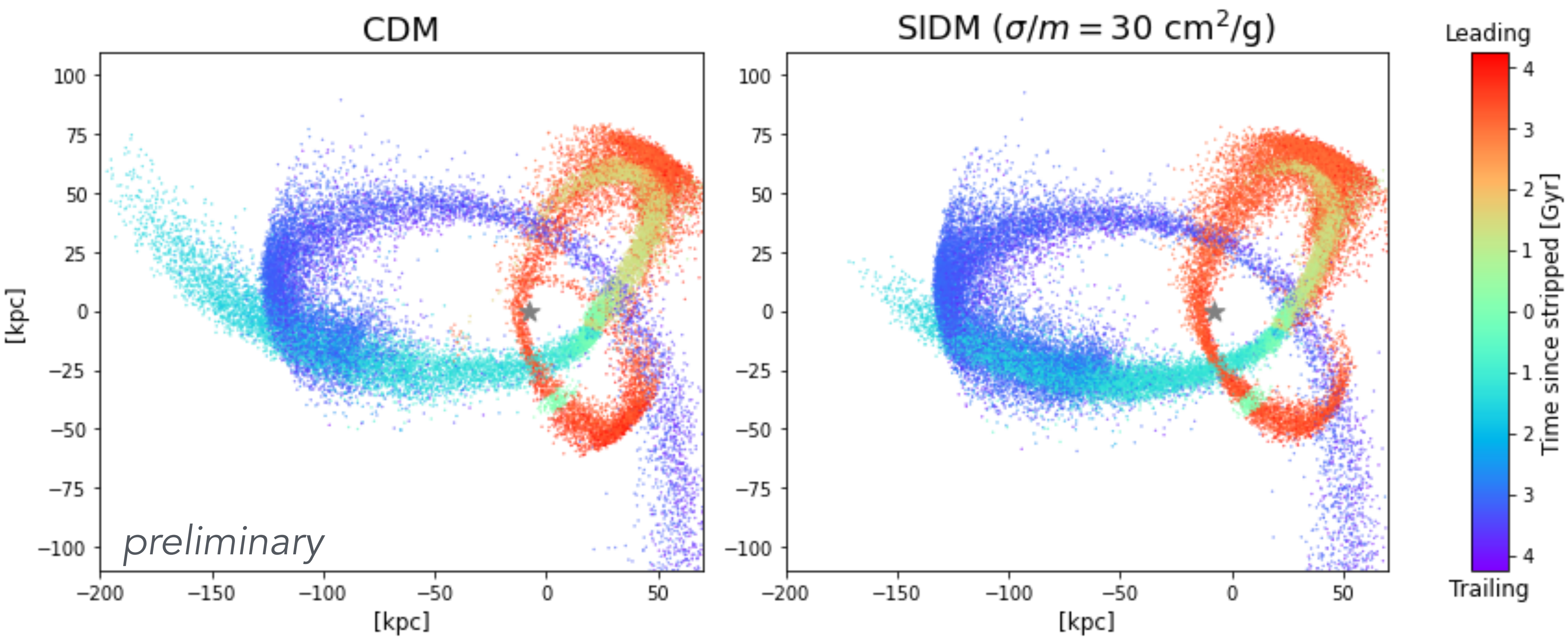
O. Slone, **ML**, M. Kaplinghat, and R. Wechsler [in prep]

Connor Hainje

Oren Slone

Sagittarius Stream

Dark matter self interactions between satellite halo and its host affect tidal mass loss, impacting stream morphology

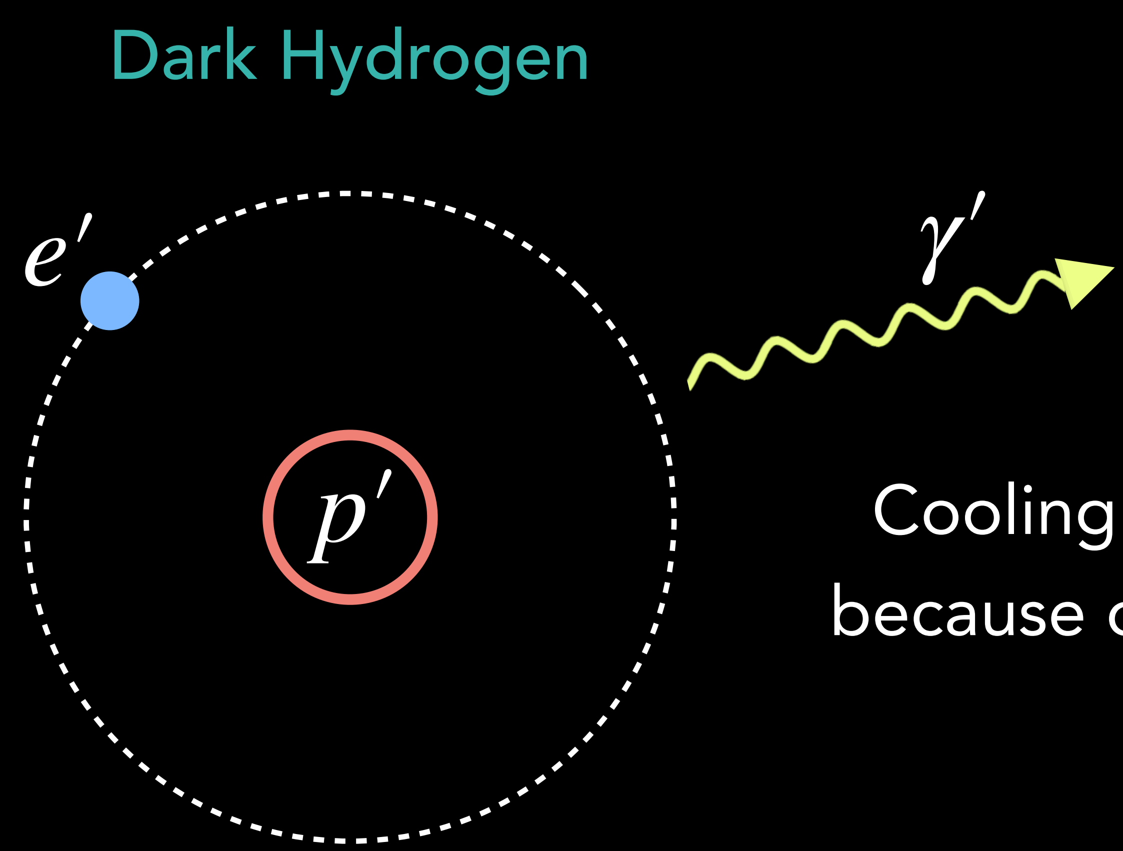


C. Hainje, O. Slone, **ML**, and D. Erkal [in prep]

Inelastic Self Interactions

If dark matter can cool, it can collapse into dark compact objects

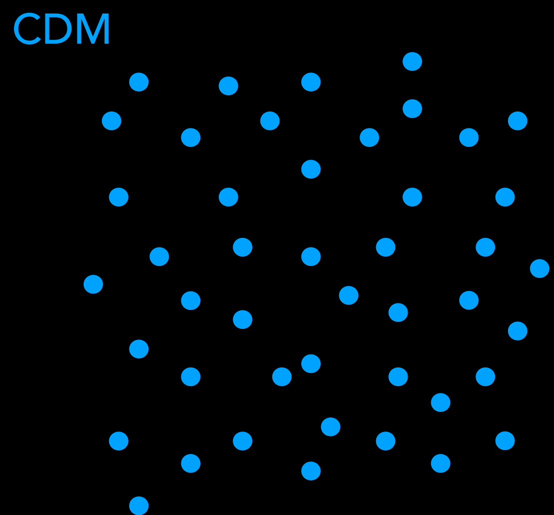
Example: Atomic Dark Matter (ADM)

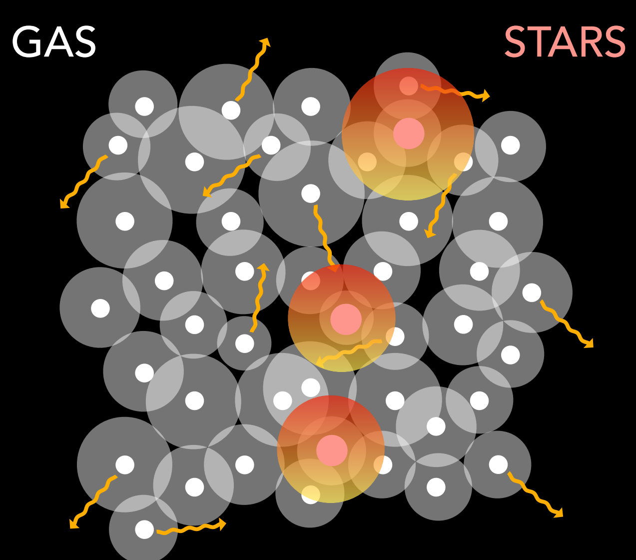


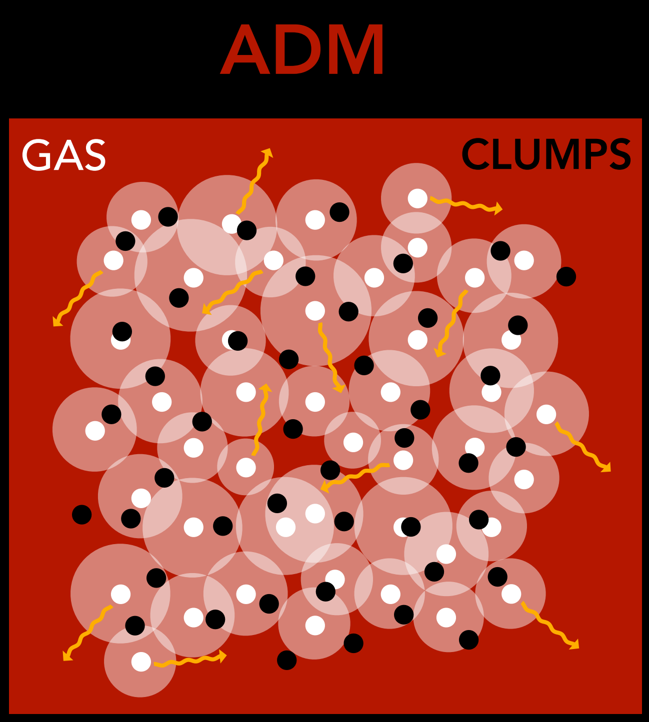
Cooling occurs in dark sector because of new dark photon (γ')

D. Kaplan et al. [0909.0753], Cyr-Racine and Sigurdson [1209.5752], J. Fan et al. [1303.1521, 1303.3271], A. Ghalsasi and M. McQuinn [1712.04779]

GIZMO + ADM Hydro Framework







Physics	**Particles**
Gravity	All
Supernovae feedback	Baryons
Cooling & collapse	Baryons & ADM

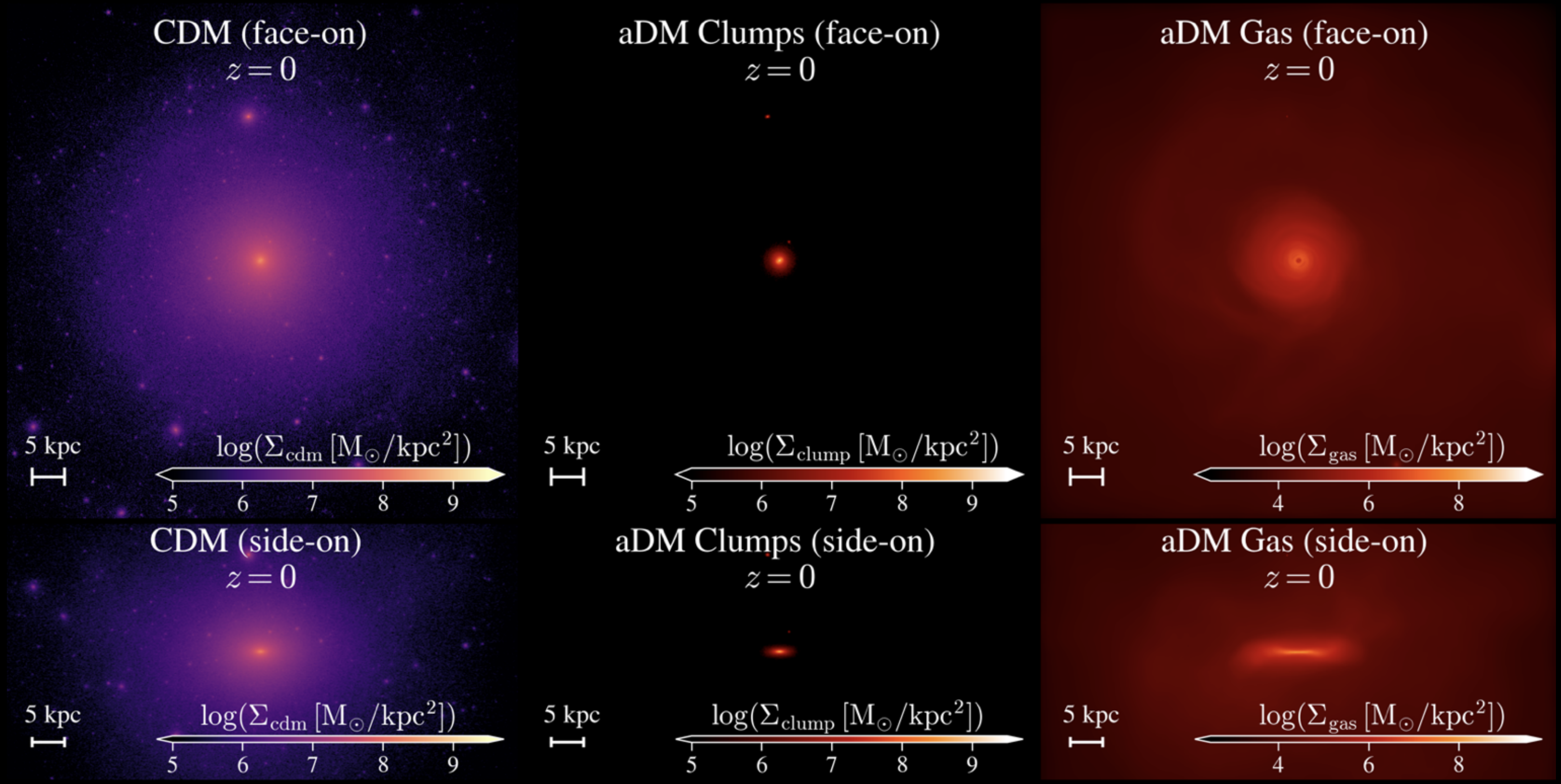

Sandip Roy


Xuejian Shen

Sandip Roy

Properties of Field Dwarfs

First simulation suite of isolated dwarf galaxies for CDM + 5% ADM

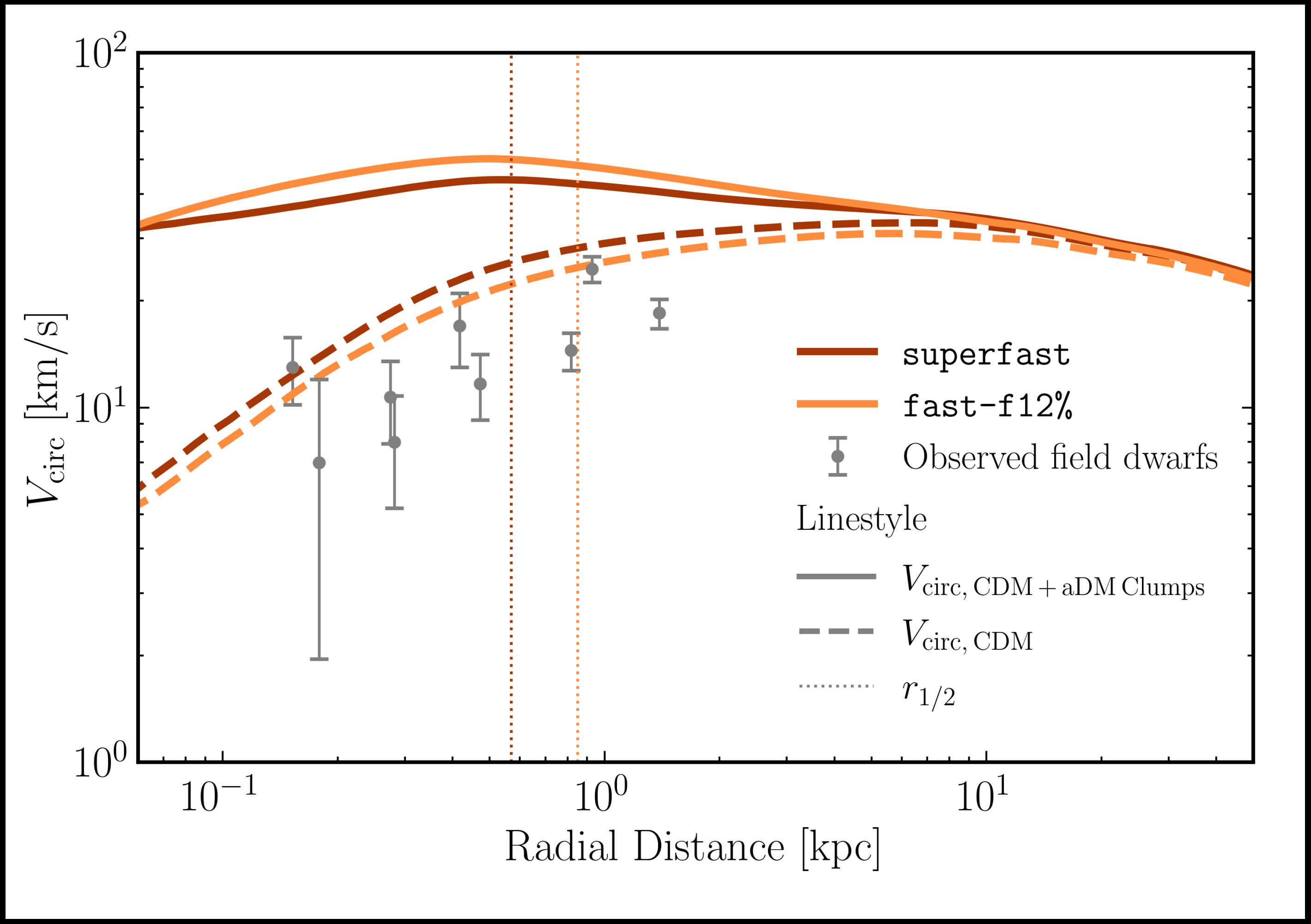


S. Roy, X. Shen, J. Barron, **ML**, D. Curtin, N. Murray, and P. Hopkins [today]

Sandip Roy

Properties of Field Dwarfs

Central density of dwarf galaxies can be significantly enhanced, providing sharp predictions for observables



S. Roy, X. Shen, J. Barron, **ML**, D. Curtin, N. Murray, and P. Hopkins [today]

Conclusions

Wealth of upcoming data will allow us to test the impact of dark matter on sub-galactic scales

Theory needs to catch up to observations:
addressing baryonic uncertainties is a top priority

Long-term goal is to make robust theory predictions for CDM and non-CDM models to harness full potential of upcoming surveys

Postdoc Acceptance Deadline

ad hoc panel appointed by the APS DPF Executive Committee is re-examining the common deadline for postdoc offers in high energy theory

To inform their final recommendations, the panel is running a survey to gather community input on the acceptance deadline

Applicants + Employers: Share Your Thoughts by September 15, 2024

APS DPF Committee

Csaba Csaki (Cornell)
Vijay Balasubramanian (UPenn)
Alejandra Castro (Cambridge)
Mariangela Lisanti (Princeton)
Hirosi Ooguri (Caltech/UTokyo)
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