Exploring the Impact of Environment on Milky Way Satellite Galaxies

Kassidy Kollmann
Princeton University

In preparation with:
M. Lisanti, J. Rose, A. Caputo, & DREAMS Collaboration

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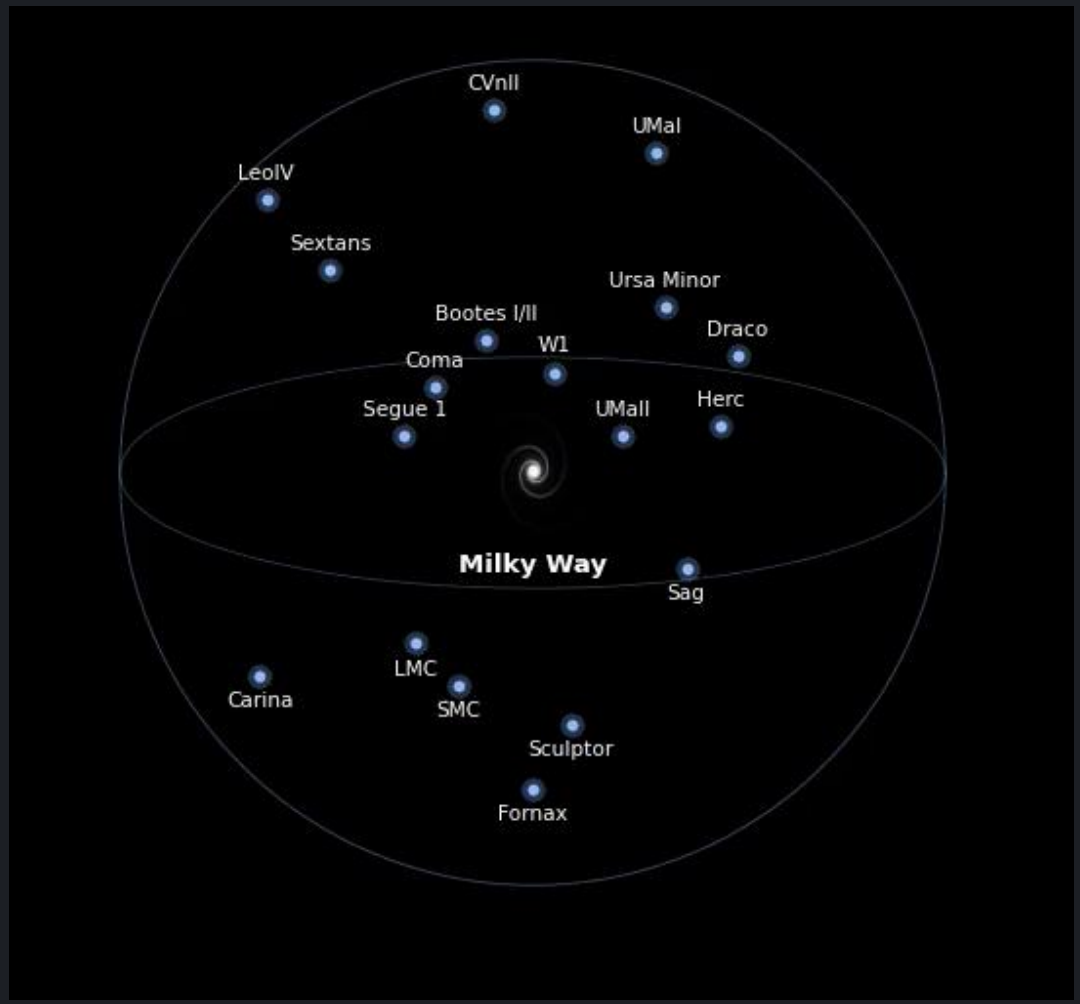
The Milky Way Galaxy

- A unique laboratory for studying small-scale structure
- Milky Way observables can constrain galaxy formation models
- How do we simulate a “Milky Way analog”?
  - Mass-matched
  - LMC-like satellite
  - Environment? Nearby massive neighbor?



DREAMS Project:

DaRk mattEr and Astrophysics with Machine learning and Simulations

Rose et al. (2025, 2026)

DREAMS Project:

DaRk mattEr and Astrophysics with Machine learning and Simulations

Rose et al. (2025, 2026)

Suite Name	Dark Matter Prescription	Baryon Prescription	# of Unique MWs	Varied Parameters	Notes
DREAMS Hydro	CDM	TNG	1024	Astrophysics & cosmology	Rose et al. (2026)
DREAMS N-body	CDM	N-body	1024	Cosmology	Rose et al. (2026)
DREAMS Environment	CDM	N-body	1024	Cosmology	**Kollmann** et al. (in prep)

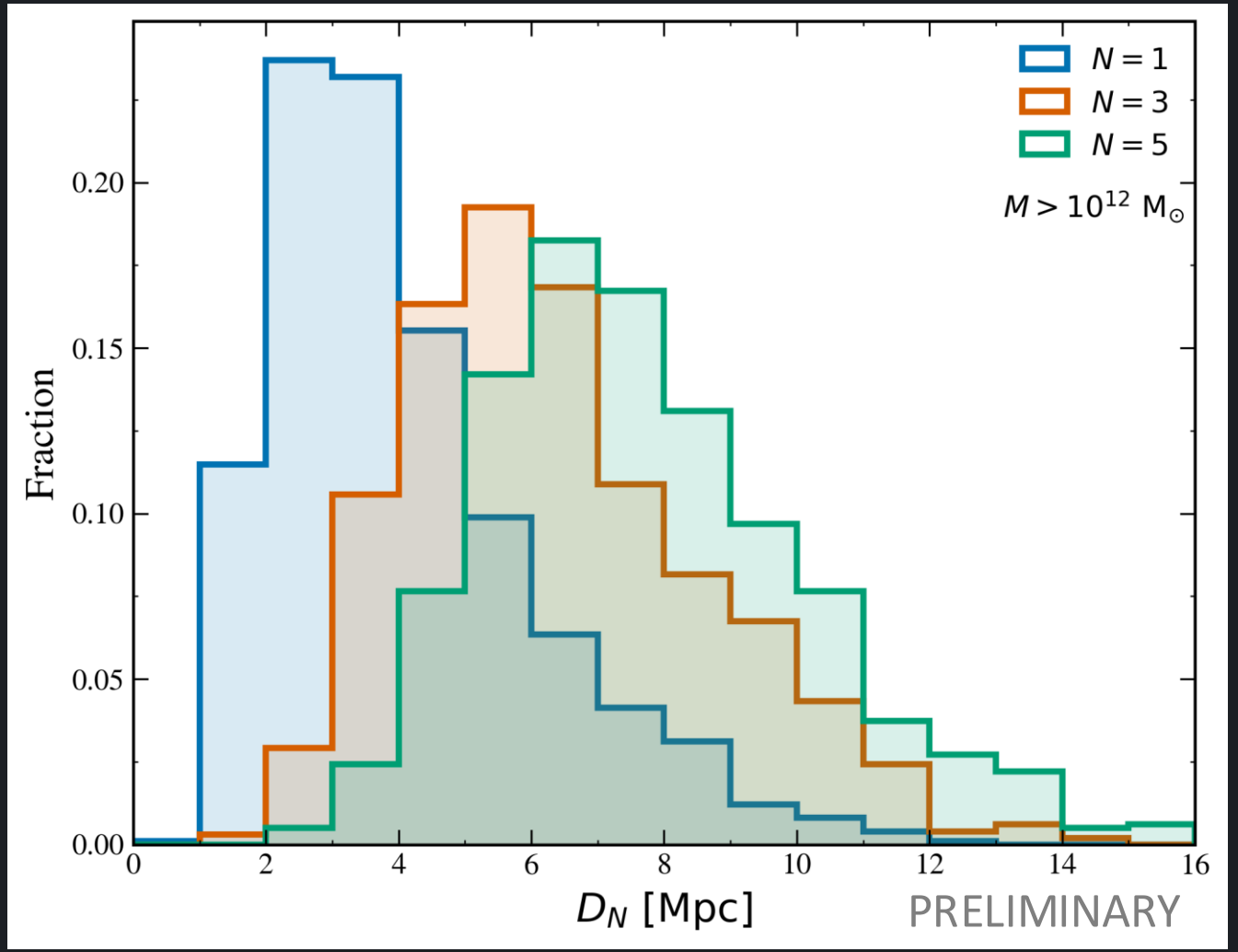
Milky Way Satellite & Environment Properties

Environment Metrics

- Distance to Nth nearest neighbor with a mass $> 10^{12}$ $M_{\odot}$
  - N = 1, 3, 5

Satellite Properties

- $\log_{10}(N_{sats})$
- Most massive satellite properties
  - $\log_{10}(M_{massive\ sat})$
  - $r_{massive\ sat}$



Nguyen et al. (2026)

NeHOD: A Generative Galaxy Emulator

$\log_{10}(N_{sats})$

$\log_{10}(M_{massive\ sat})$

$r_{massive\ sat}$

Trained on the DREAMS Milky Way data

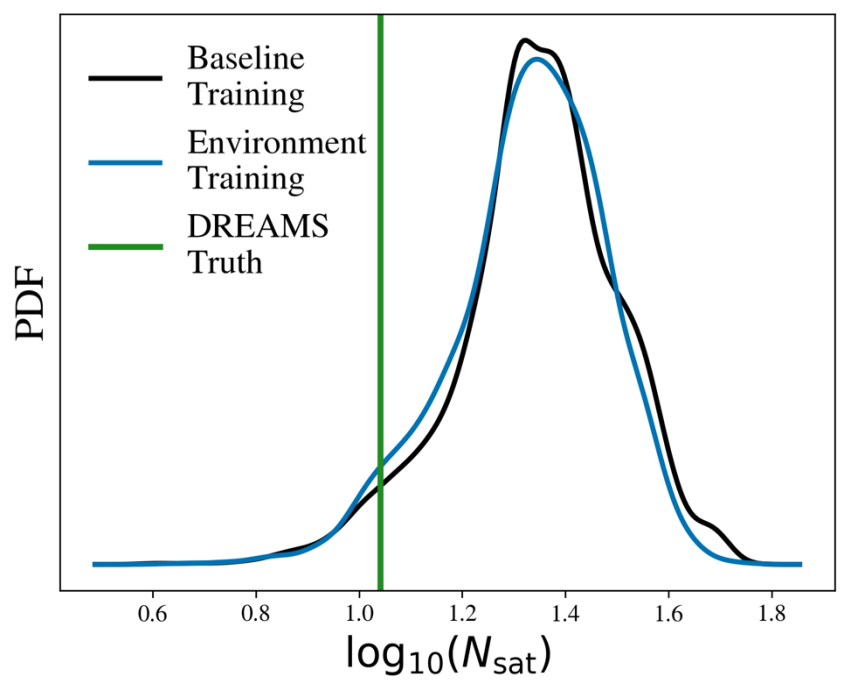
- Uses a normalizing flow to model $p(x|y)$
- **Inputs:**
  - **MW halo mass**
  - **Simulation parameters**
  - **+ Environment metric $(D_{N=1})$**
- **Outputs:**
  - **Satellite properties**

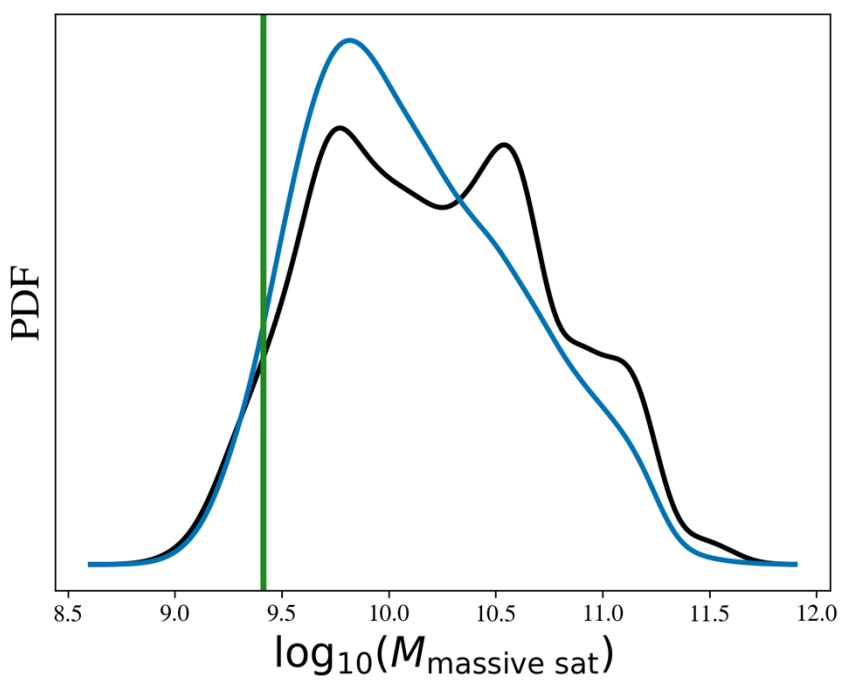
Emulating DREAMS Galaxies

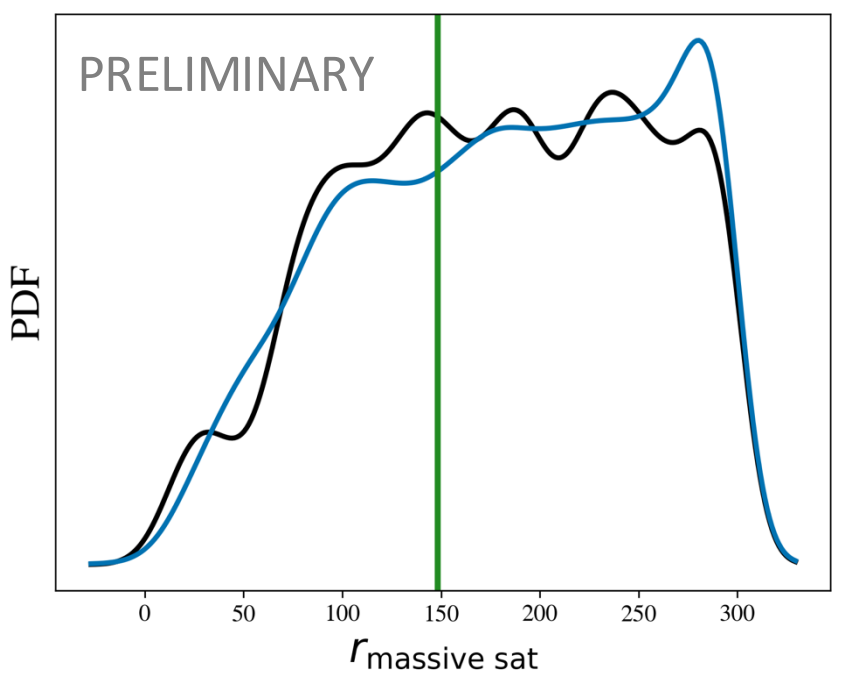
For a specific DREAMS Milky Way, generate 100,000 emulated galaxies by inputting the DREAMS galaxy's properties.

Does adding environment information provide additional predictive power for satellite properties?

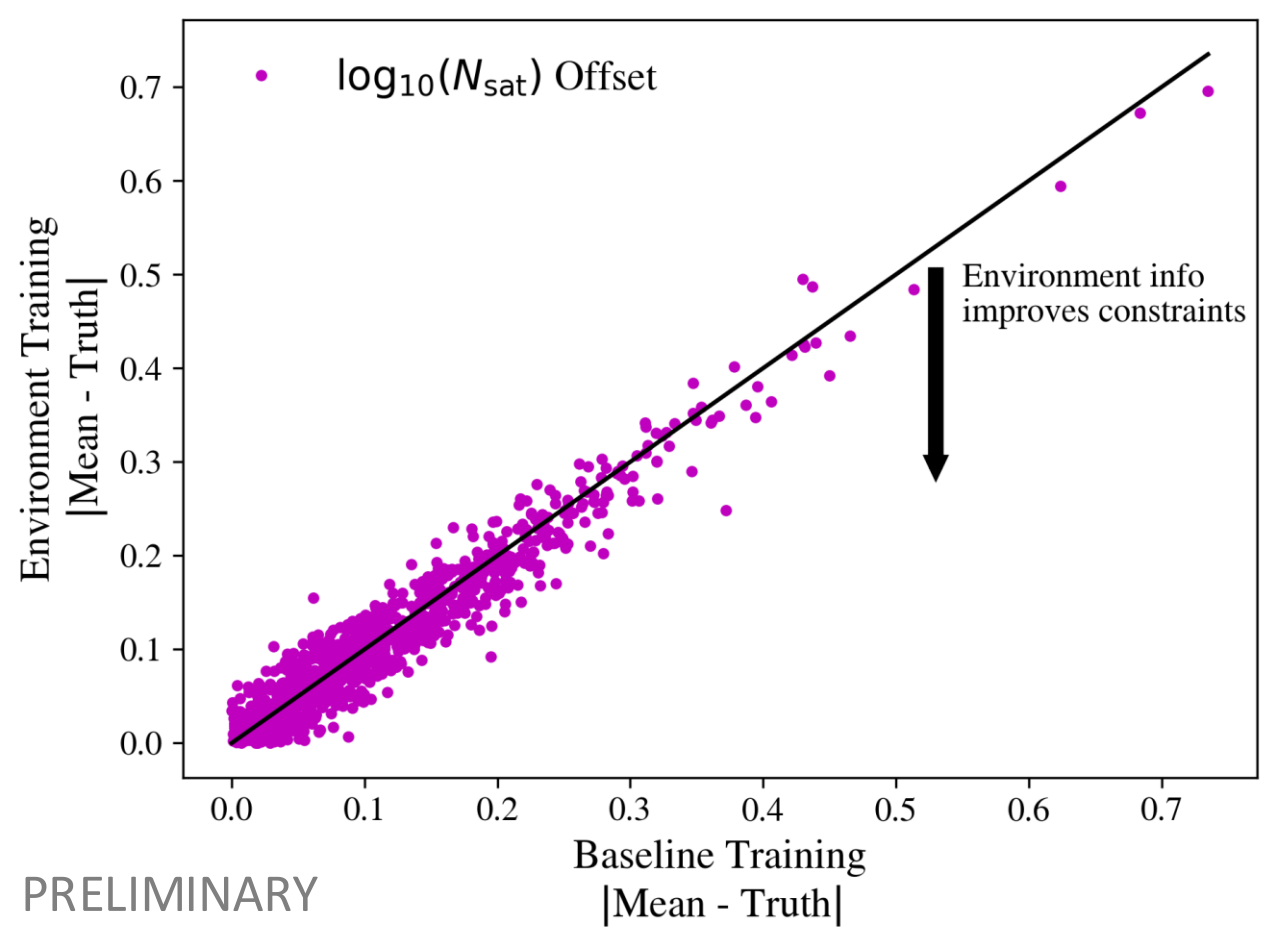
Constraints with $D_{N=1}$ - one DREAMS MW

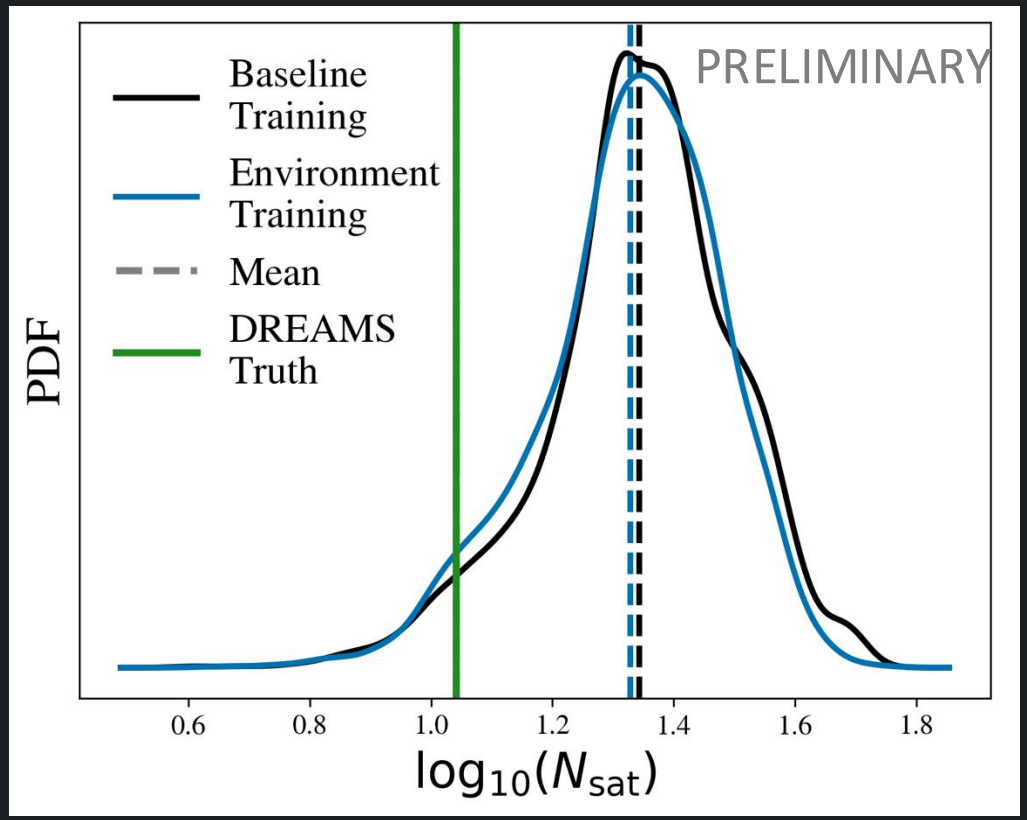




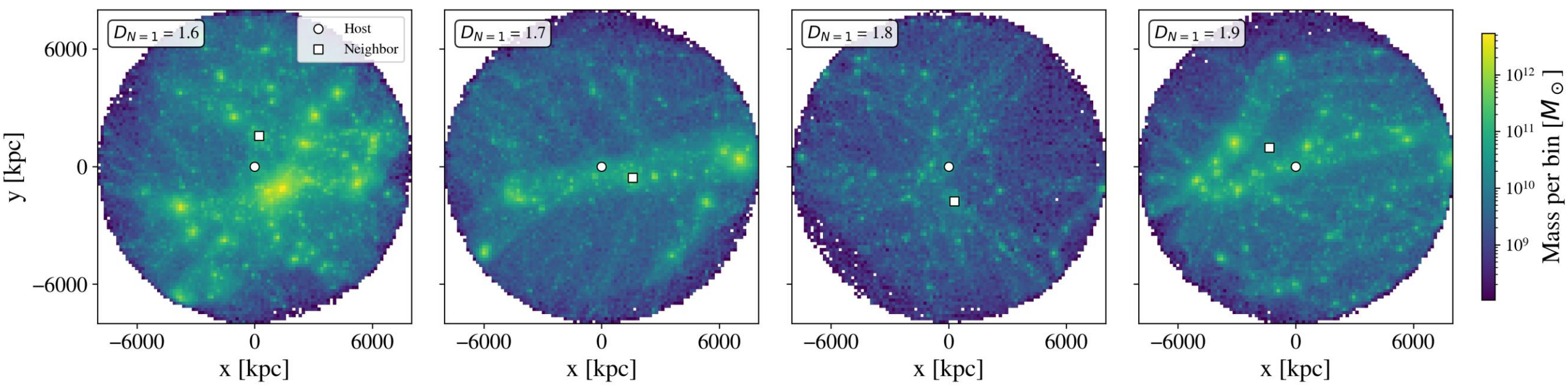


Constraints with $D_{N=1}$ - all DREAMS MW



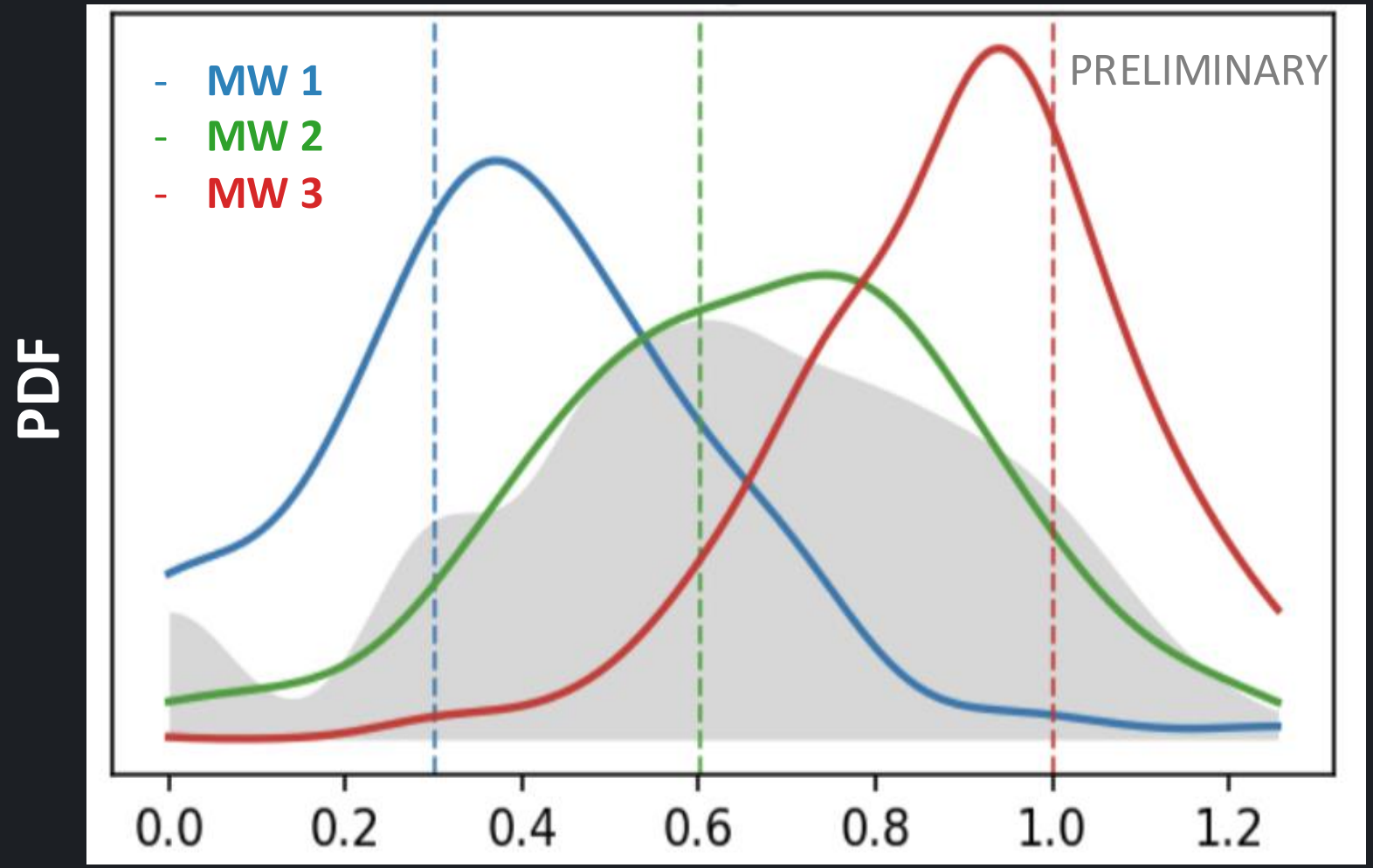


How well do summary statistics quantify environment?



Constraints with Density Field

Credit:
Carol Cuesta-Lazaro



Conclusions

- No correlation between the satellite properties and environment summary statistics explored in this work
  - Summary statistics may not be strong quantifiers of environment
- Promising results when using density field to quantify environment

Future Work

- Cosmic web classification
- New DREAMS simulation suites
  - Local Group Suite
  - Milky Ways with LMCs

Extra Slides

DREAMS Simulation Details

Simulation Suite Name	# of Sims	High Res Region Particles Selected	Baryon Prescription	Mass Resolution $[h^{-1}\Omega_{\rm m}{\rm M}_\odot]$	Gravitational Softening [kpc]	Reference
DREAMS Hydro	1024	$5R_{200}$	TNG	4.0×10^6	0.441	J. C. Rose et al. (2025a)
DREAMS N-body	1024	$5R_{200}$	N-body	4.0×10^6	0.441	J. C. Rose et al. (2025a)
DREAMS Environment	1024	8 Mpc	N-body	2.5×10^8	1.764	This paper

Table 1. Summary of the three CDM zoom-in simulation suites of Milky Way-mass galaxies from the DREAMS Project. Column 1: the name used to refer to each simulation suite throughout this work. Column 2: the number of simulations in each suite. Column 3: all particles within this distance of the target halo at $z = 0$ are traced back to $z = 127$ to define the high resolution simulation region. Column 4: the galaxy formation model used for each suite, if any. Column 5: the dark matter particle mass resolution for each suite divided by the value of $\Omega_{\rm m}$ (which varies throughout each suite). Column 6: the gravitational softening of each suite at $z = 0$. Column 7: the original work introducing each simulation suite. The DREAMS Hydro and DREAMS N-body suites were first presented in J. C. Rose et al. (2025a). The DREAMS Environment suite is presented in this work.

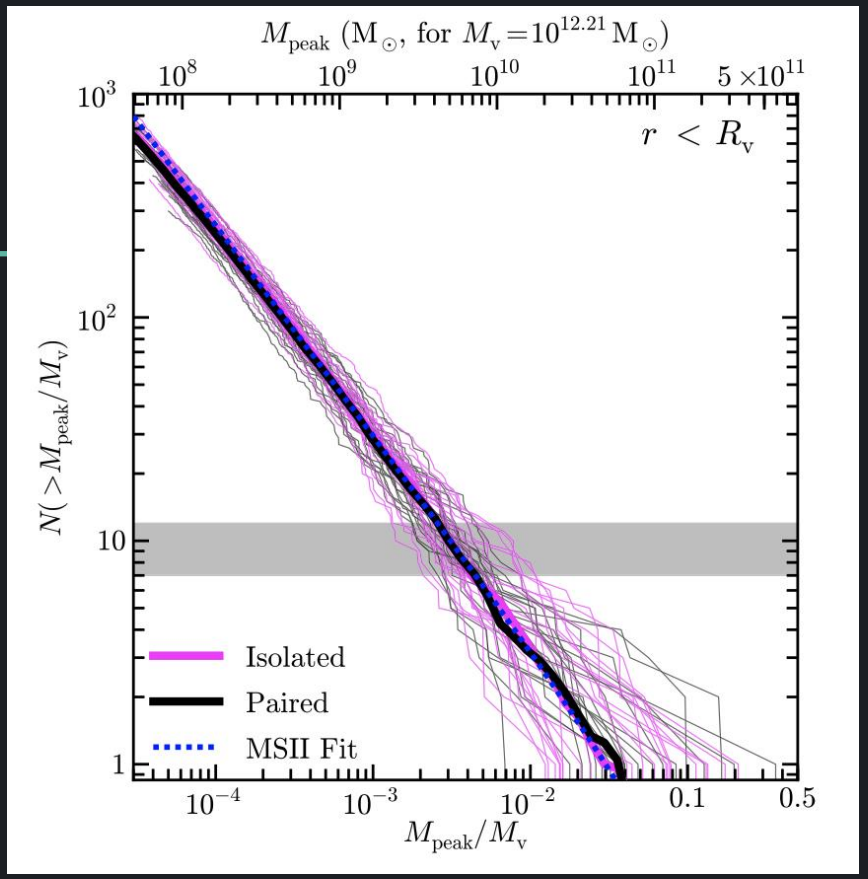
Kollmann et al. in prep

The Milky Way's Environment

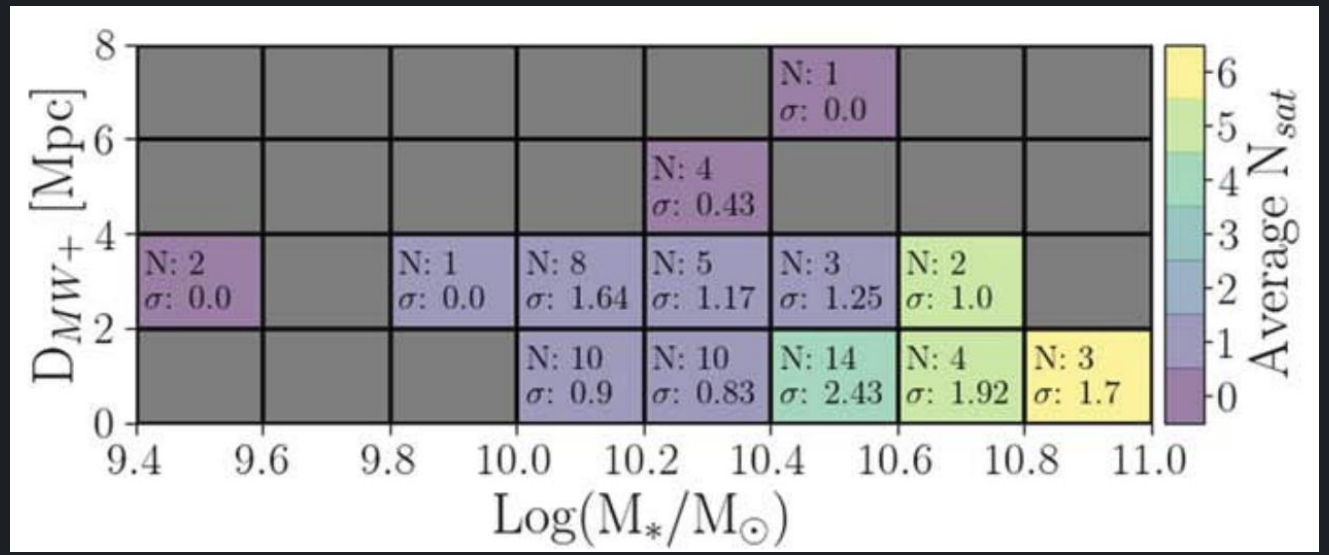
Environment Metrics:

- Isolated versus paired
- Nearest neighbor distance
- Galaxy number density:
  - Fixed count
  - Fixed volume

$$\rho_N = \frac{N}{\frac{4}{3}\pi r^3}$$



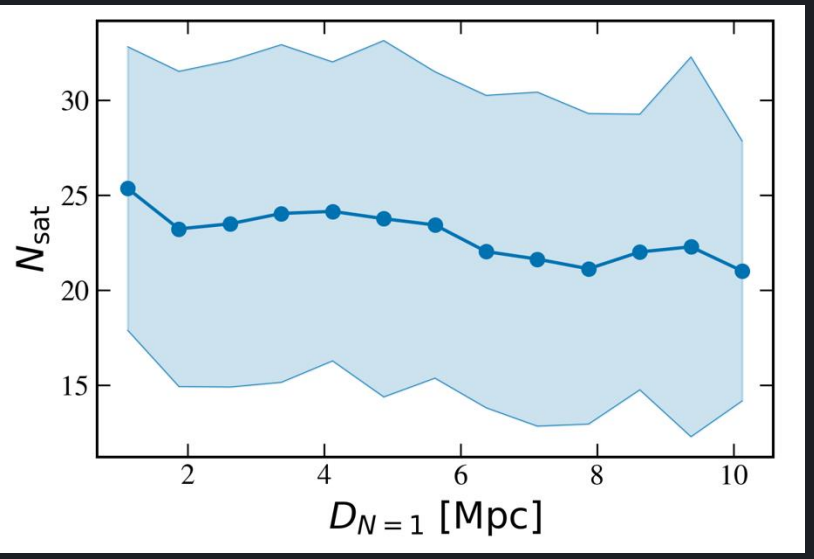
Garrison-Kimmel et al. (2014)
ELVIS: Exploring the Local Volume in Simulations



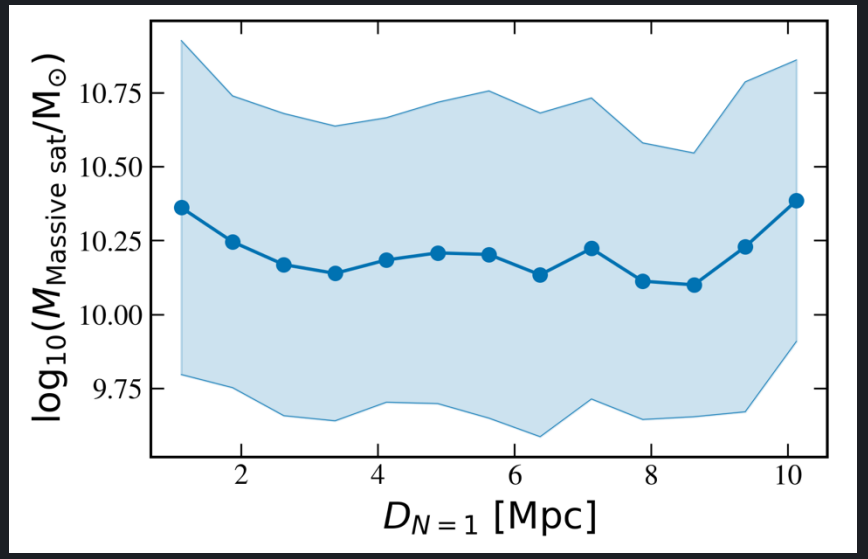
Van Nest et al. (2023)
ROMULUS25 Simulation

Milky Way Satellite & Environment Properties

N_{sats}



Most massive satellite
$\log_{10}(M_{massive\ sat})$



Most massive satellite
$r_{massive\ sat}$