StreamGen:
Connecting Semi-analytic Tidal Debris to Dark Matter Halos

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DGSCS - July 10, 2024

z=0.77

Galaxy assembly
FIRE

100 kpc

Video credit: FIRE collaboration, Wetzel et al. 2016, Hopkins et al. 2018 2

Milky Way streams

Shipp et al. 2018, Li et al. 2019, Malhan et al. 2022, Miró-Carretero et al. 2023

Extragalactic tidal debris

Rubin, Roman +others, will discover thousands of disrupting satellites in galaxies out to tens of Mpc

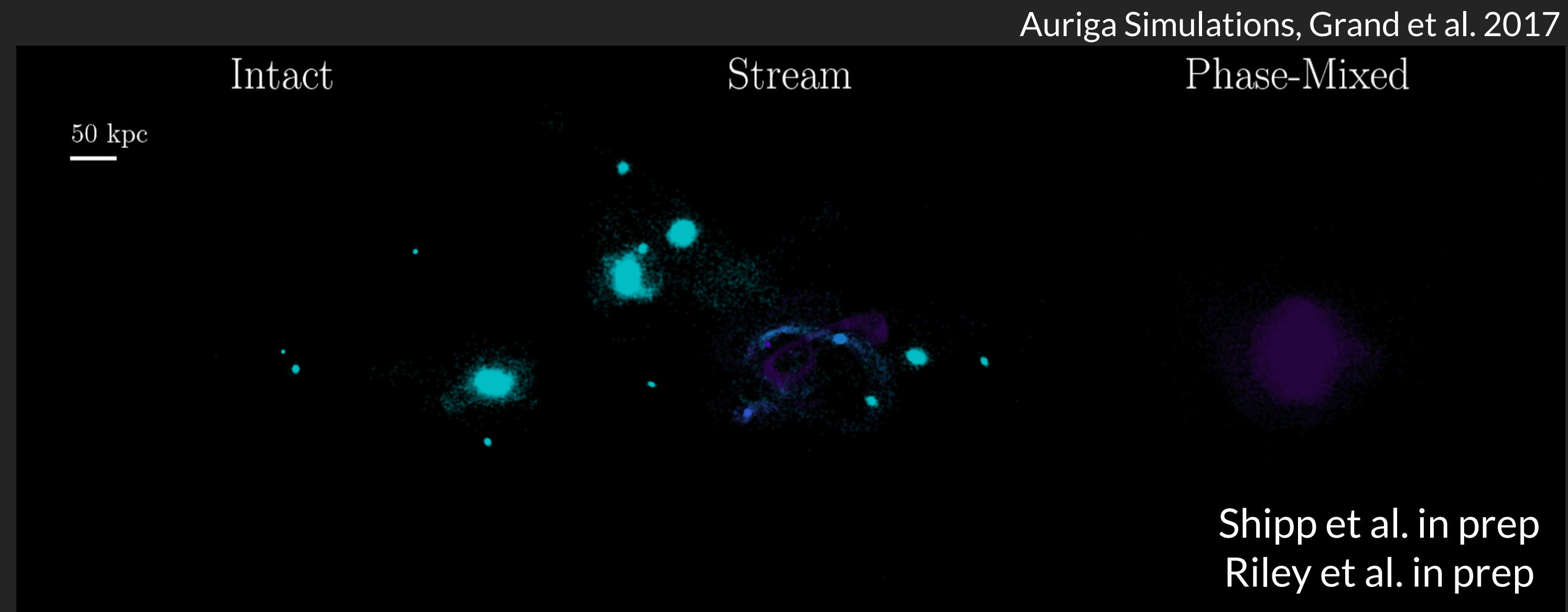For the first time, we'll have population statistics of tidal debris in data!

Shang et al.1998; Martin et al.2014; Martinez-Delgado et al.2021; Martınez-Delgado et al.2012; Toloba et al.2016a; Kado-Fong et al.2018; Carlin et al.2019; Kado-Fong et al.2020 Ivezic et al. 2008, Laureijs et al. 2011, Spergel et al. 2013, Laine et al. 2018

Martinez-Delgado et al. 2021

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Tidal debris populations are powerful tools

- More complete picture of galaxy formation and diversity

- Robust understanding of tidal disruption

  - Baryonic solution to questions about ΛCDM

  - Satellite structure connected to dark matter properties

- Statistics!

Auriga Simulations, Grand et al. 2017

Intact   Stream   Phase-Mixed

50 kpc

Shipp et al. in prep
Riley et al. in prep

Wetzel et al. 2016; Garrison-Kimmel et al. 2017; Fitts et al. 2017; Simpson et al. 2018; Garrison-Kimmel et al. 2019; Buck et al. 2018; Kim et al. 2018; Sales et al. 2022;Du et al. 2018; Tulin & Yu 2018; Kaplinghat et al. 2020; Eckert et al. 2022; Shen et al. 2022; Penarrubia et al. 2012; Errani et al. 2015,2022

Tidal disruption varies with host properties

- Potential of host galaxy

  - Affected by disk properties

  - Baryonic feedback

- History of mass loss

- Substructure in the halo/ mergers

Bursty Feedback

Smooth Feedback

SPICE simulations, Bhagwat et al. 2024

Penarrubia et al. (2010),
Garrison-Kimmel et al. 2017,
Jiang et al. 2021

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Streams in sims

Hydro

- Particle-level information allows for studies of tidal stripping, dynamical friction, baryonic feedback

- Understand impact of mergers

- Mock catalogs

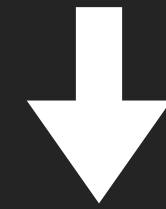Hopkins 2015; Hopkins et al. 2018, 2022; Grand et al. 2017; Agertz et al. 2021; Applebaum et al. 2021

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7

FIRE vs. Milky Way

Shipp et al. 2023

- FIRE streams have higher pericenters and apocenters than Milky Way streams

- Difficult to study systematic uncertainties on orbital properties
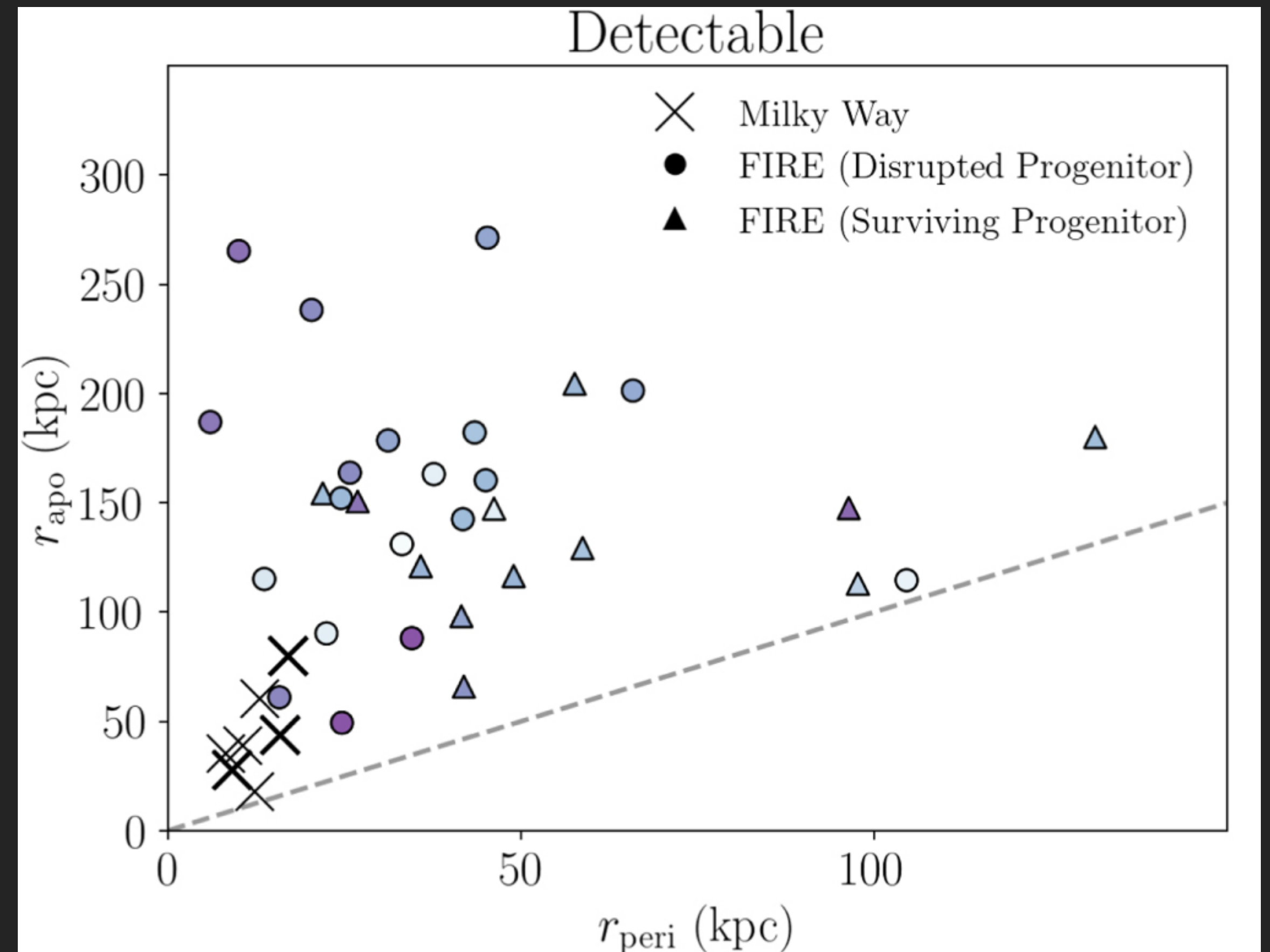
We need a method to rapidly evolve assembly histories to substructure and identify morphology to gain a clearer understanding of tidal disruption.

Stream generation

Hydro	Semi-analytic

Hydro

- Particle-level information allows for studies of tidal stripping, dynamical friction, baryonic feedback

- Understand impact of mergers

- Mock catalogs

Semi-analytic

- Understand halo response, halo-to-halo variance

- No artificial disruption due to low resolution

- Population statistics

Hopkins 2015; Hopkins et al. 2018, 2022; Grand et al. 2017; Agertz et al. 2021; Applebaum et al. 2021

Benson et al. 2010, Jiang & van den Bosch 2016, Nadler et al. 2019, Jiang et al. 2019, Yang et al. 2020
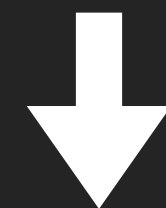
StreamGen

1. Generate fiducial galaxies using SatGen

⬇

2. Apply morphology metric to subhalos
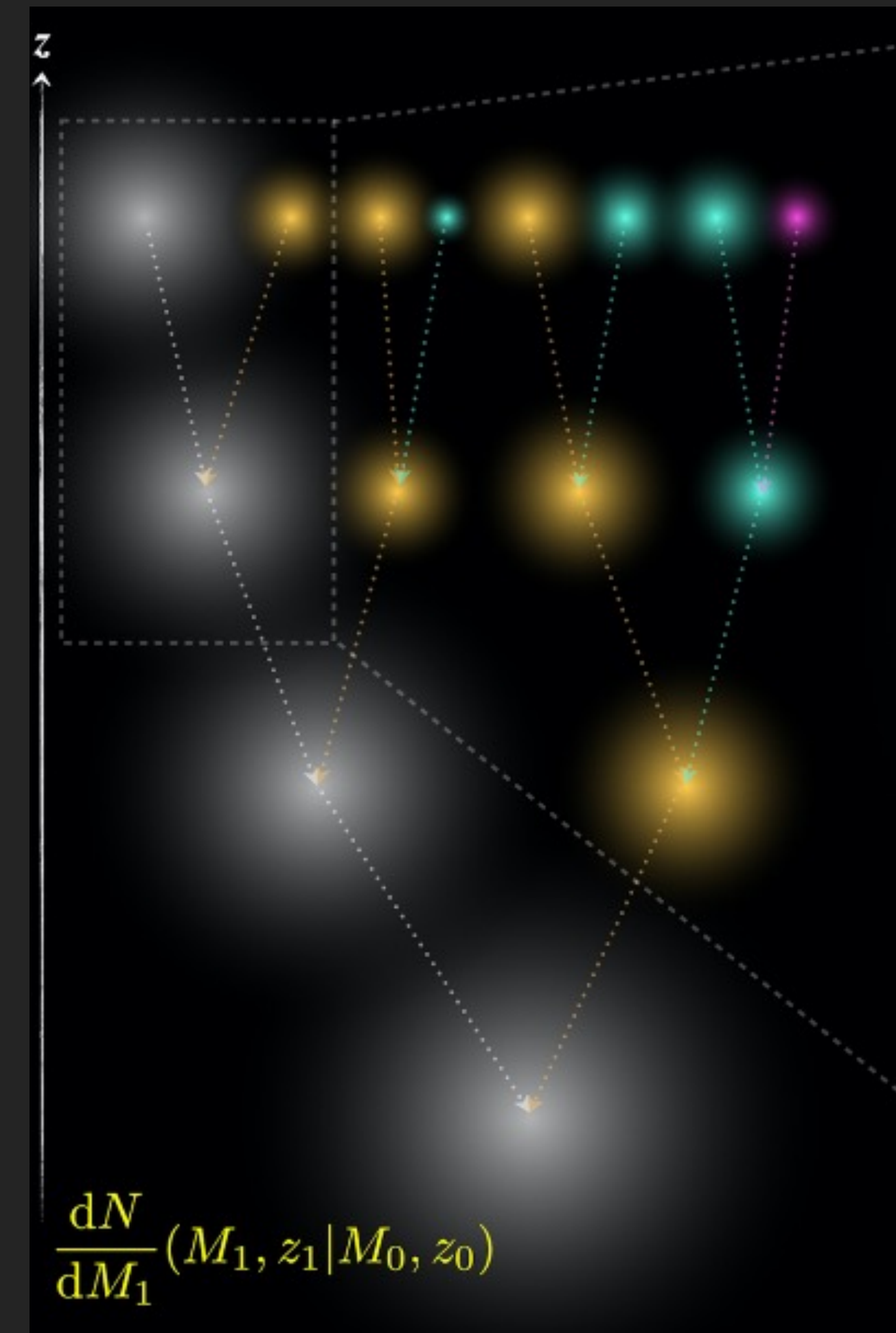
⬇

3. Examine orbital distribution of streams

⬇

4. Modify fiducial model and repeat 1 - 3

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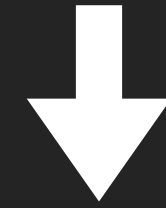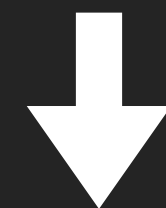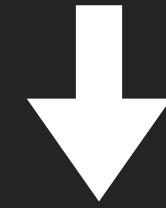
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SatGen: a semi-analytic satellite galaxy generator

Jiang et al. 2019

- Dark matter halo merger trees

- Halos have analytic profiles

- Empirical relations for galaxy-halo connection

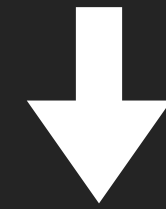- Tidal stripping, RAM pressure stripping, dynamical friction

$$\frac{dN}{dM_1}(M_1, z_1 | M_0, z_0)$$

Jiang et al. 2019

Parkinson et al. 2008, Benson 2017,
Rodriguez-Puebla et al. 2017, Kravtsov 2013,
Somerville et al. 2018, Penarrubia et al. 2008 & 2010,
Errani et al. 2015, 2018, 2021, Freundlich et al. 2020,
Dekel et al. 2017

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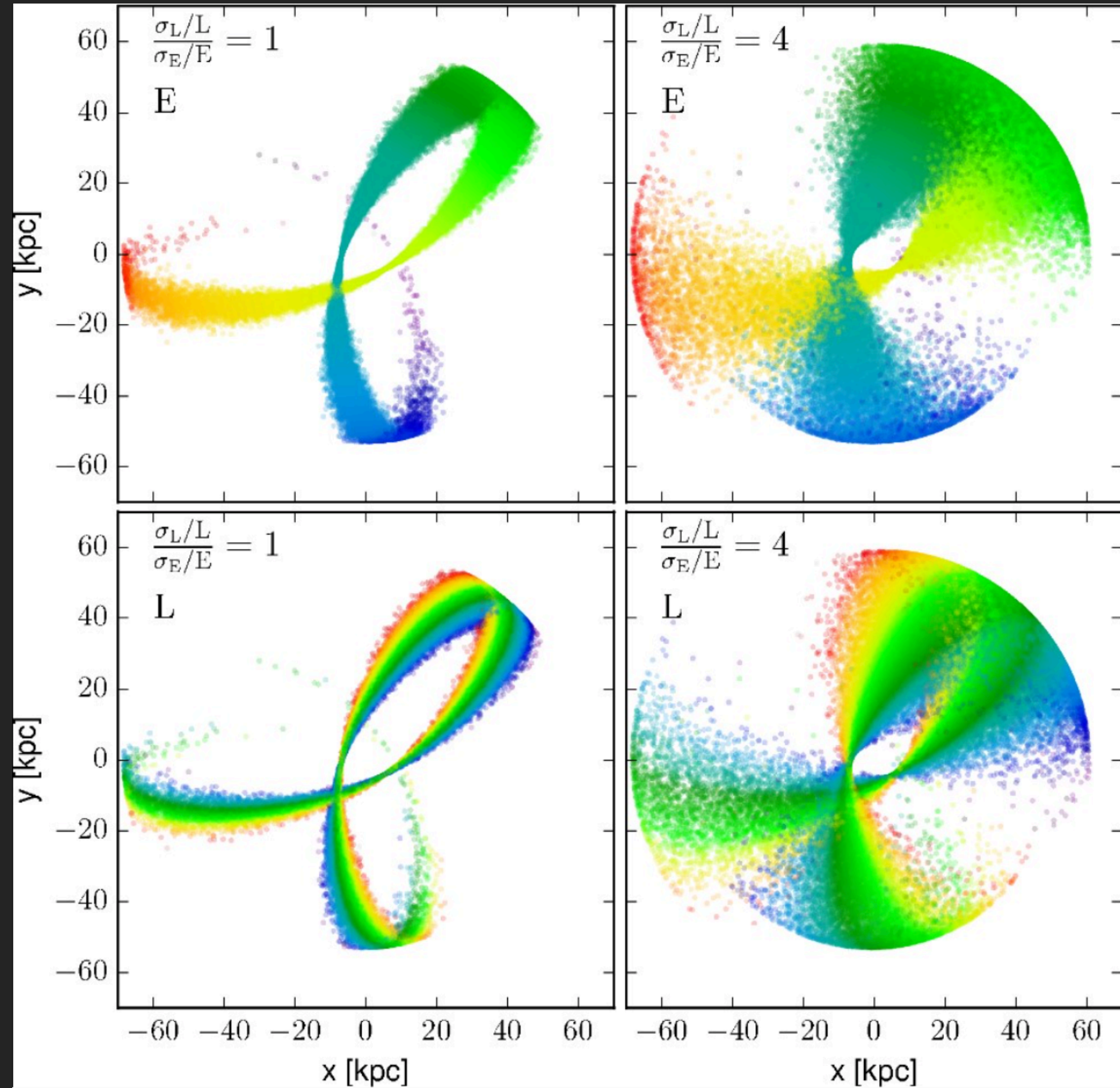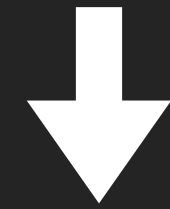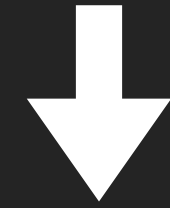
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15
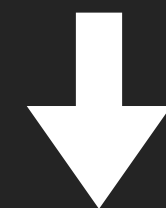
The morphology metric

Hendel and Johnston 2015

Stream-like   Shell-like

High energy to low energy

High angular momentum to low

Intact if lost < 10% of peak stellar mass

Semi-analytic host galaxy models
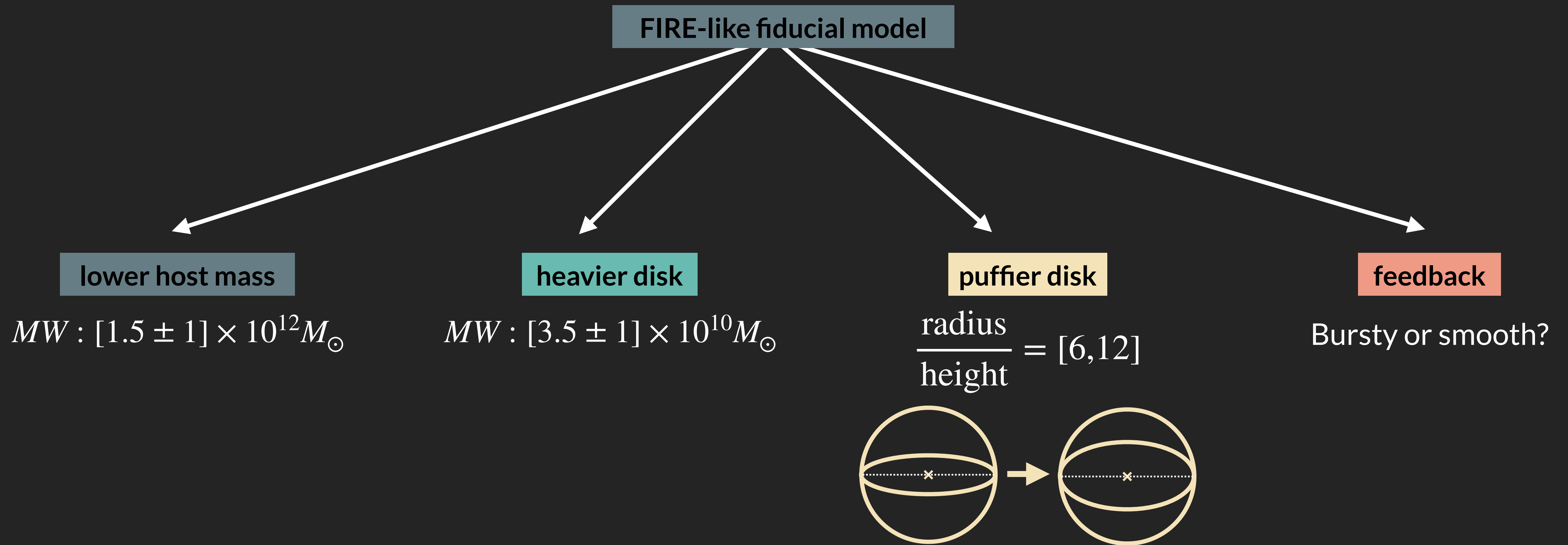
FIRE-like fiducial model

lower host mass   heavier disk   puffier disk   feedback

$MW : [1.5 \pm 1] \times 10^{12} M_{\odot}$ $MW : [3.5 \pm 1] \times 10^{10} M_{\odot}$

$$\frac{\text{radius}}{\text{height}} = [6,12]$$

Bursty or smooth?

Bobylev & Bajkova (2023),
Bland-Hawthorn
& Gerhard (2016)

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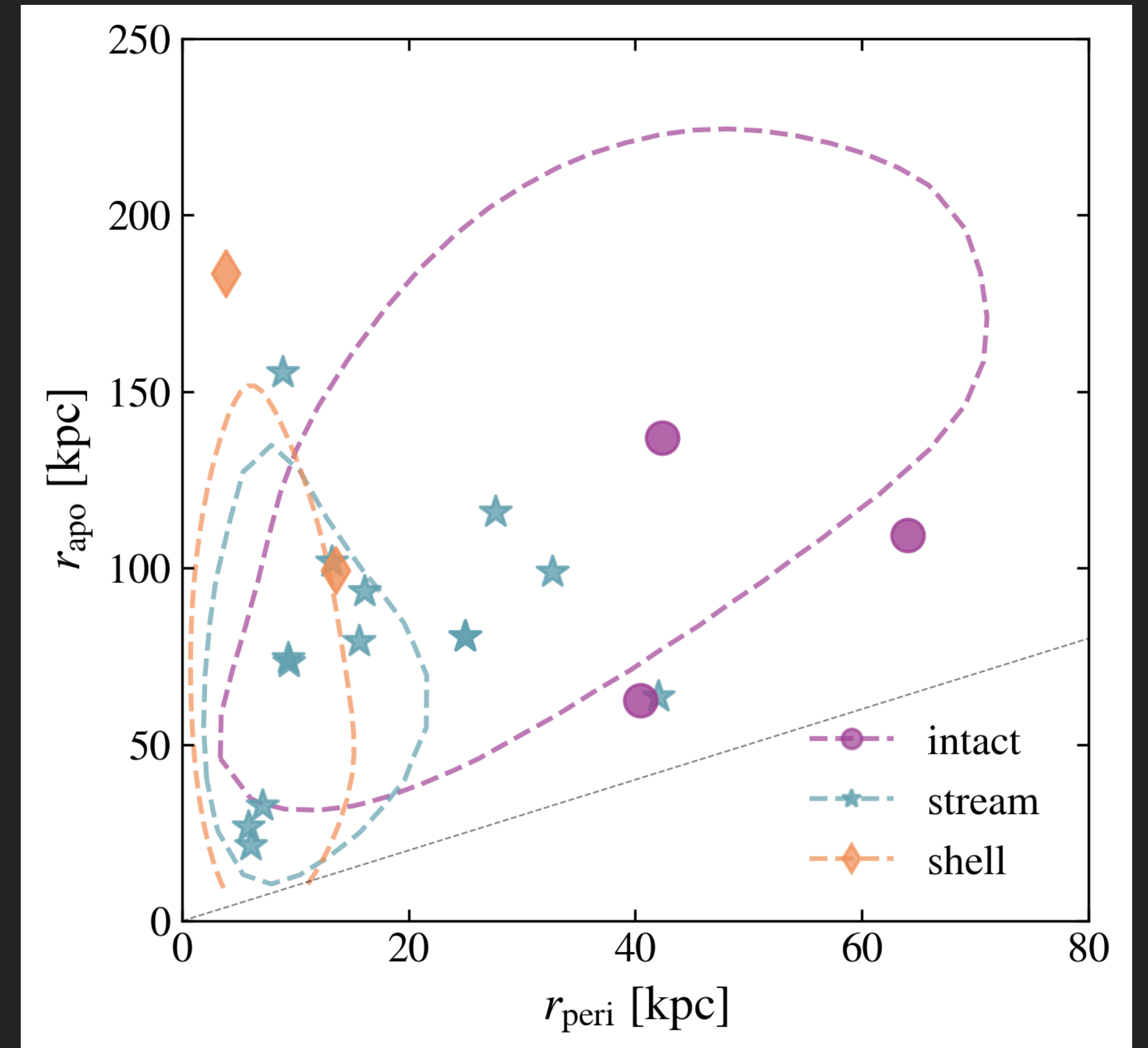
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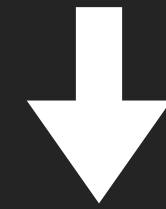# Semi-analytic tidal debris population statistics

350 FIRE-like galaxies

- $M_*, \mathrm{acc} > 5 \times 10^5 M_\odot$

- $r_{\mathrm{sat-host}} > 4$ kpc

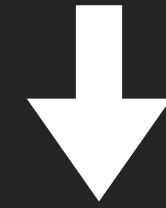- Eccentric orbits and close to disk - high mass loss!

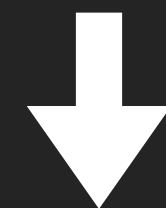Dropulic et al. 2024 (in final prep)

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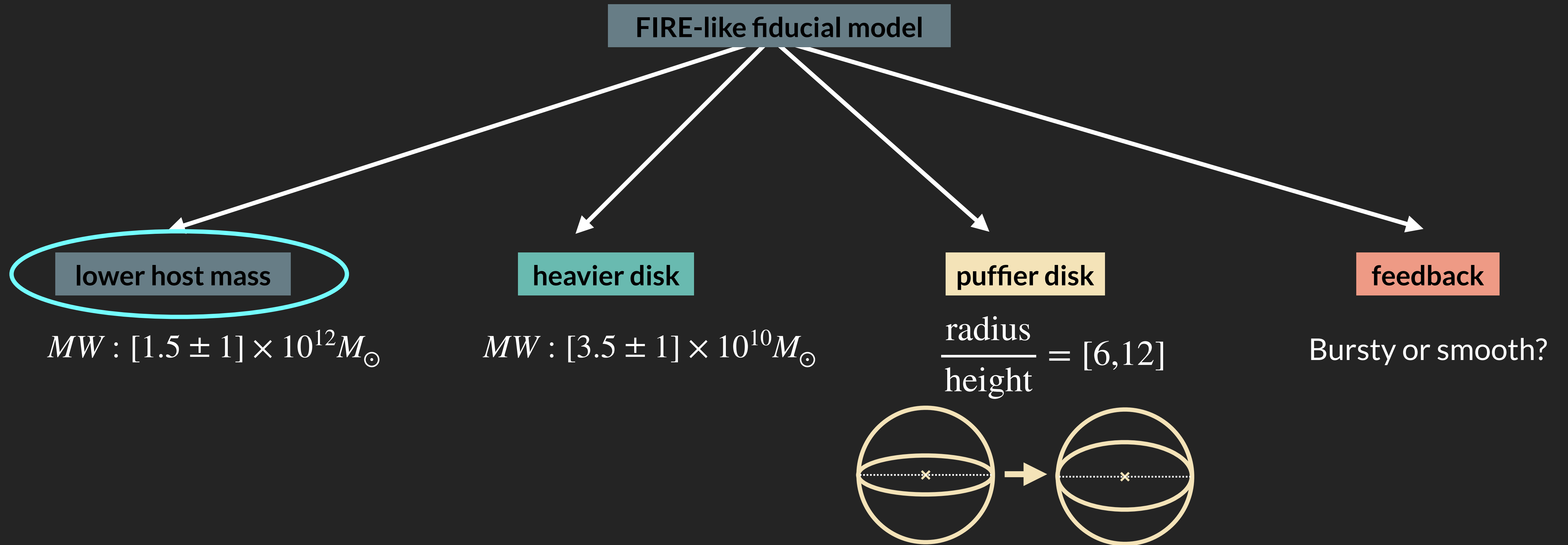
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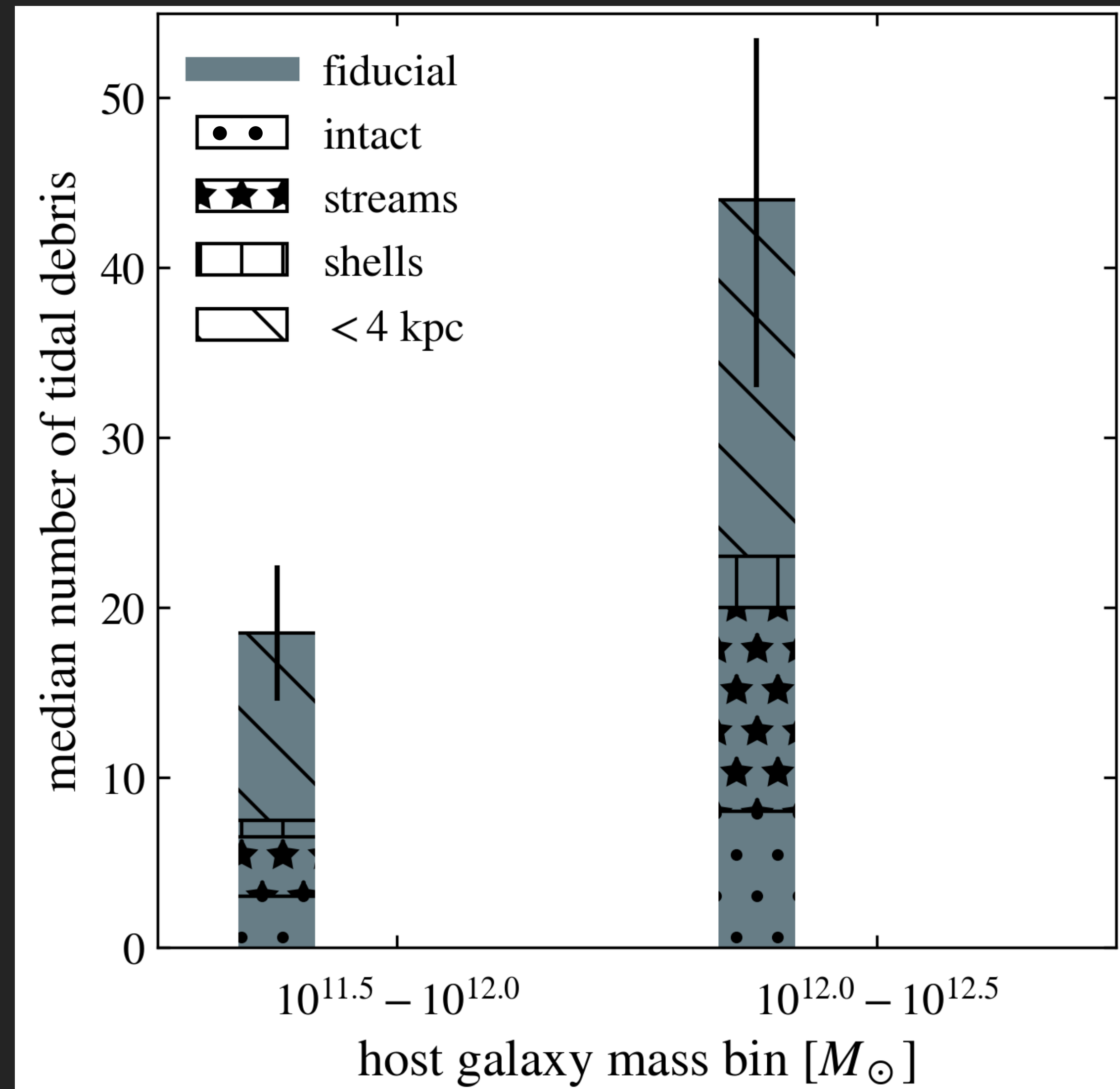
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Semi-analytic host galaxy models

FIRE-like fiducial model

lower host mass

heavier disk

puffier disk

feedback

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Median tidal debris abundances across halo models

$M_*, \mathrm{acc} > 5 \times 10^5 M_\odot$

Median tidal debris fractions across halo models

$M_*, \text{acc} > 5 \times 10^5 M_\odot$

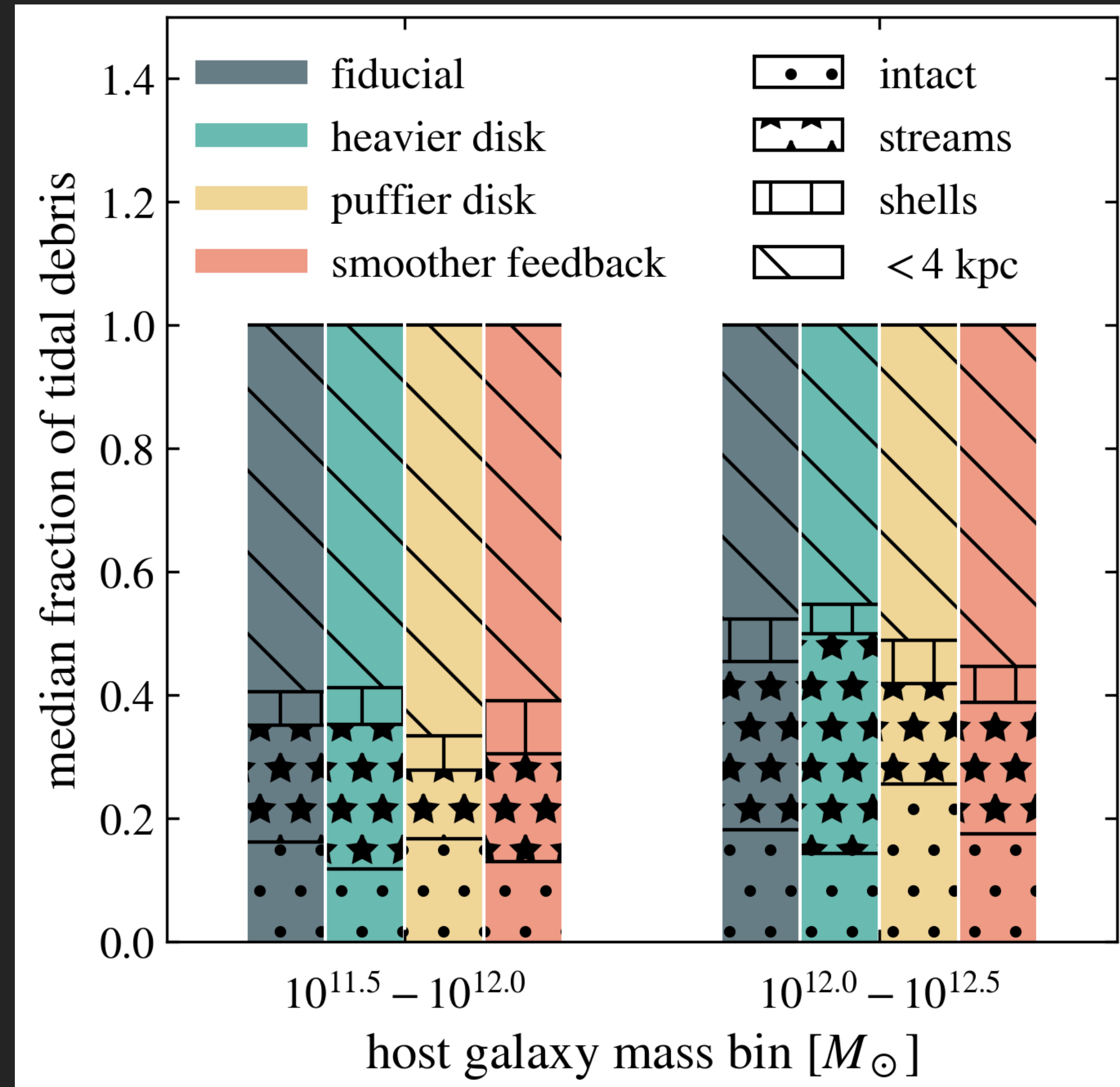Now looking at
fraction of tidal debris
instead of abundance!

Median tidal debris fractions across halo models

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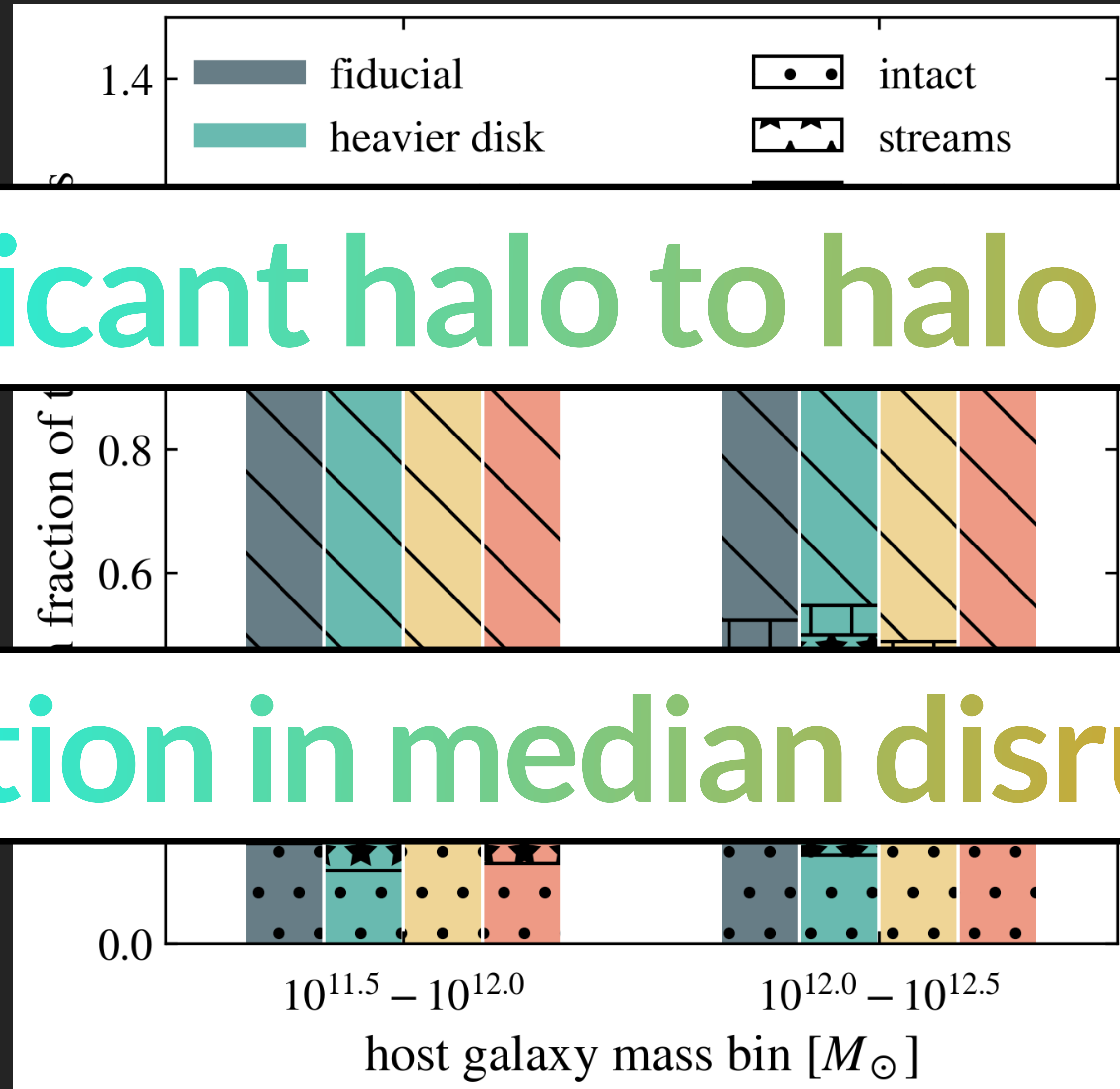
Dropulic et al. 2024 (in final prep)

Median tidal debris fractions across halo models
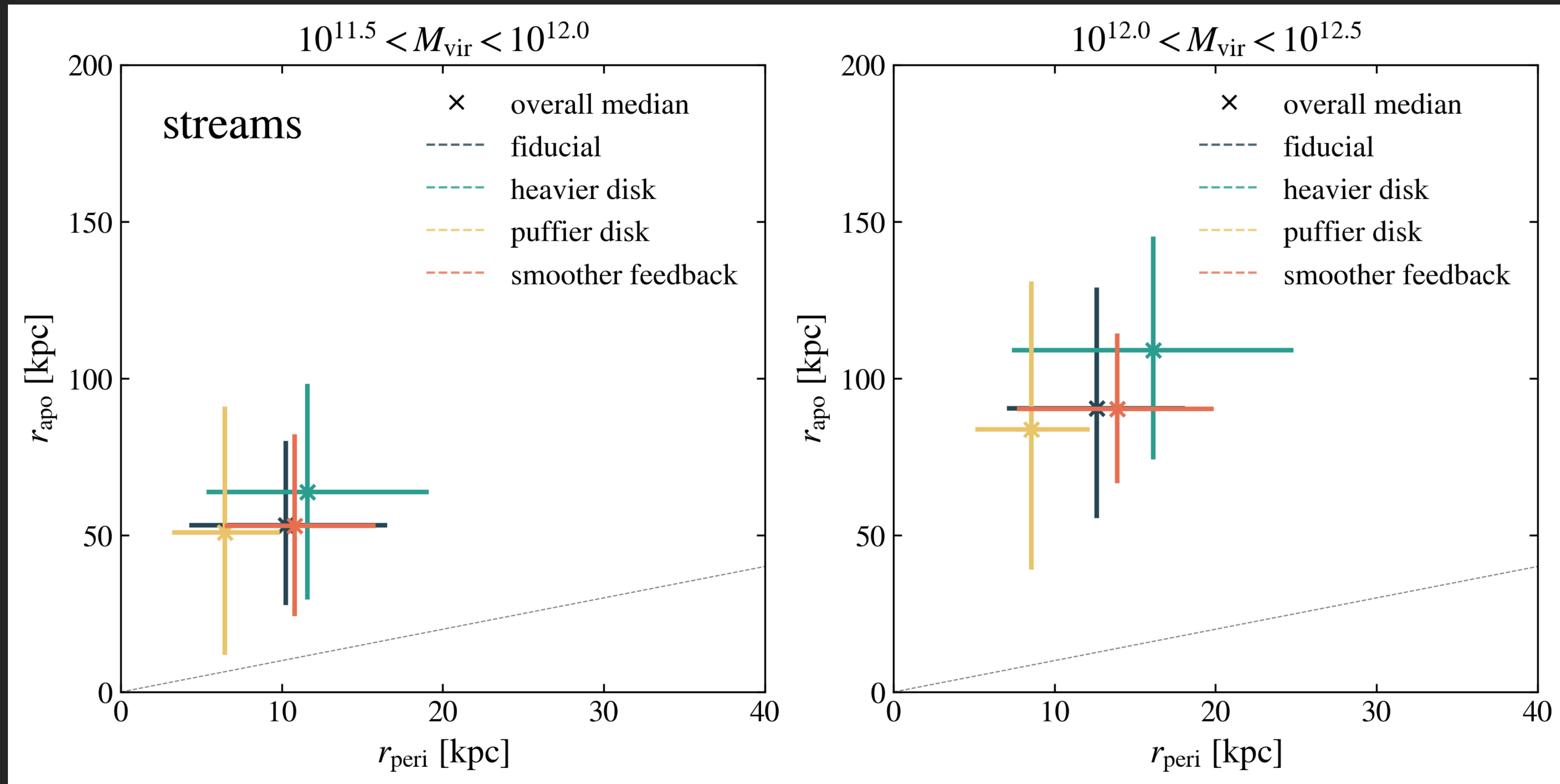

M_*, acc

Significant halo to halo variance

Now looking at fraction of tidal debris instead of abundance!

Variation in median disruption

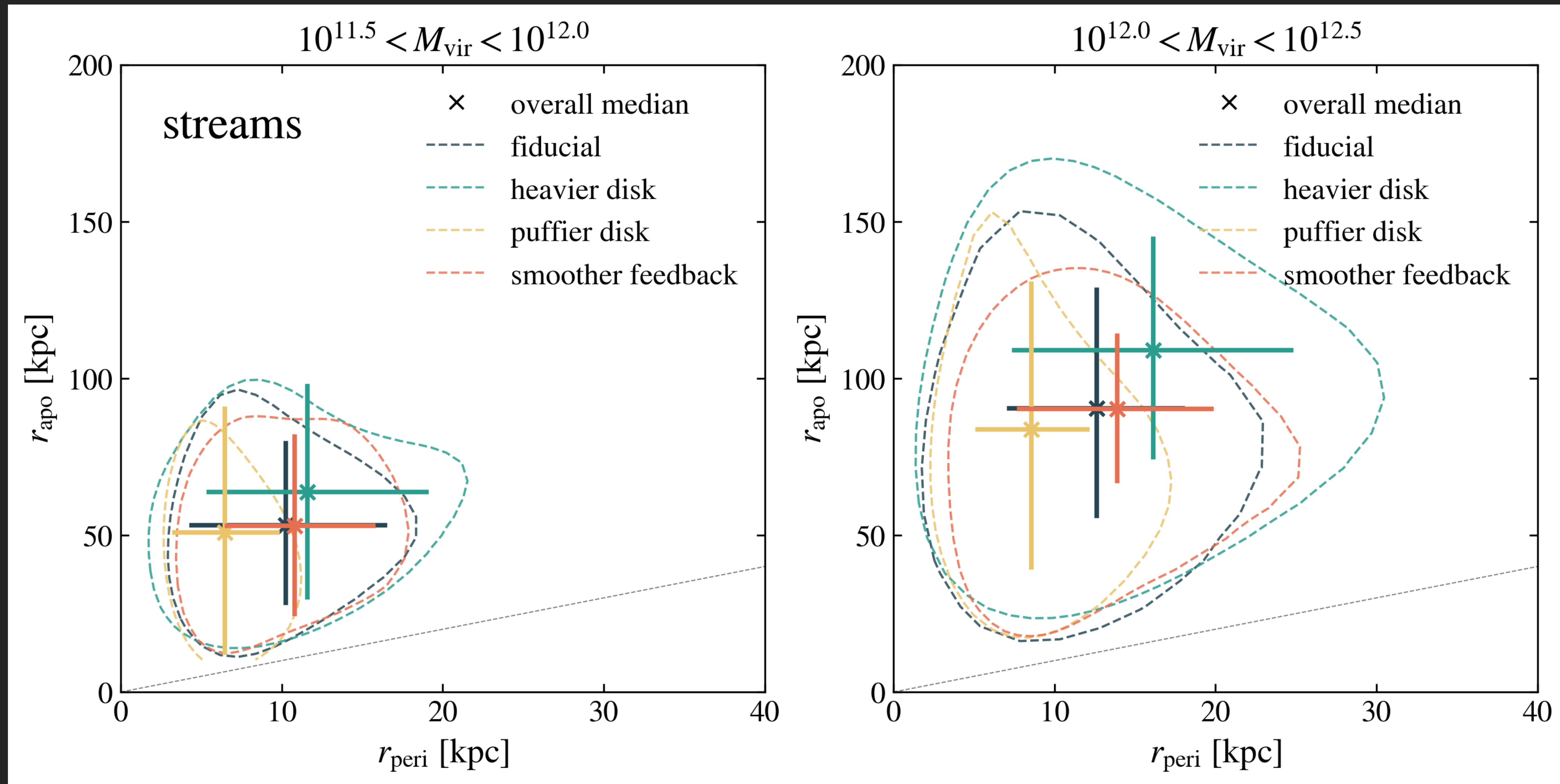Legend: fiducial, heavier disk, intact, streams

fraction of t ... fraction of t

1.4 — 0.8 — 0.6 — 0.0

$10^{11.5} - 10^{12.0}$ $10^{12.0} - 10^{12.5}$

host galaxy mass bin [$M_\odot$]

Dropulic et al. 2024 (in final prep)

Stream orbits across halo models

Stream orbits across halo models

$10^{11.5} < M_{\rm vir} < 10^{12.0}$

$10^{12.0} < M_{\rm vir} < 10^{12.5}$

streams

× overall median
fiducial
heavier disk
puffier disk
smoother feedback

× overall median
fiducial
heavier disk
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smoother feedback

$r_{\rm apo}$ [kpc]

$r_{\rm peri}$ [kpc]

Dropulic et al. 2024 (in final prep)

StreamGen: Key Takeaways

- New tool to study populations of disrupting satellites!

- Halo-to-halo variance is most significant effect , but variations in host properties systematically change median orbital distributions

- Future: complement cosmological simulations in modeling stellar debris and facilitating comparisons with data from e.g. Rubin and Roman