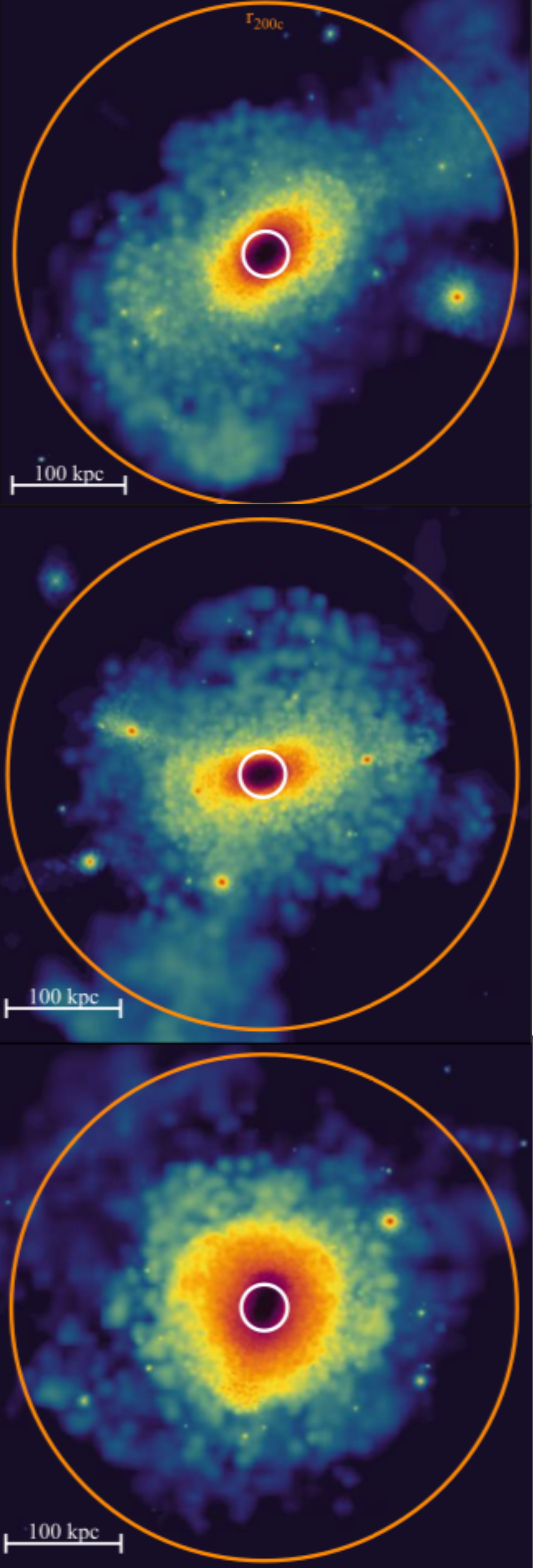
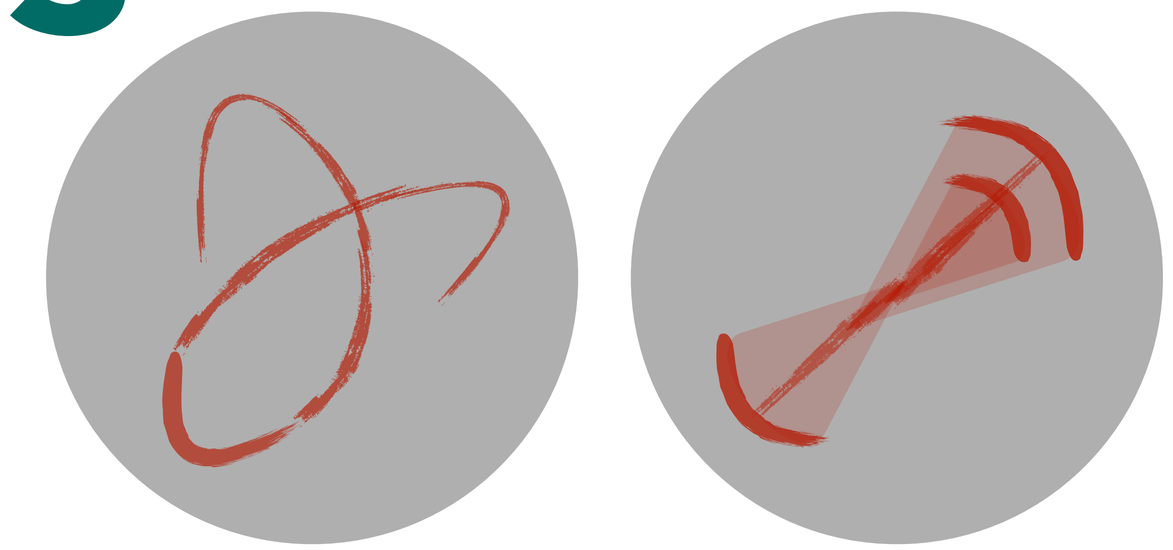


The formation and observability of stellar halos and tidal features in external galaxies



Tjitske Starkenburg
CIERA, Northwestern University

In collaboration with:
Martin Rey (Oxford), Sarah Pearson (NYU),
Kathryn Johnston (Columbia/CCA),
Rachel Somerville (Rutgers/CCA)

STELLAR HALOS AND SATELLITE DEBRIS PROVIDE A WEALTH OF INFORMATION

- Stellar halos provide clues to a *galaxy's past evolution* and provide insights on *low-mass galaxy formation* (e.g. Helmi & White 1999; Cole+2000; Johnston+2001; Bullock+2001; Bullock & Johnston 2005; Bell+2008; Lowing+2015; Amorisco 2017; Monachesi+2019; Merritt+2020; Cook+2016; Helmi+2018; Donlon+2020; Renaud+2021; Bullock & Johnston 2005; Deason+2021; Cunningham+2021, …)

- Extended and/or cold streams trace the host potential providing key constraints on *dark matter halo properties* (e.g. Johnston+1999, 2001, 2002; Law & Majewski 2010; Varghese+2011; Lux+2013; Vera-Ciro+2013; Bonaca+2014; Sanders 2014; Bovy+2016; Sanderson+2017; Bonaca+2018; Reino+2020, …)

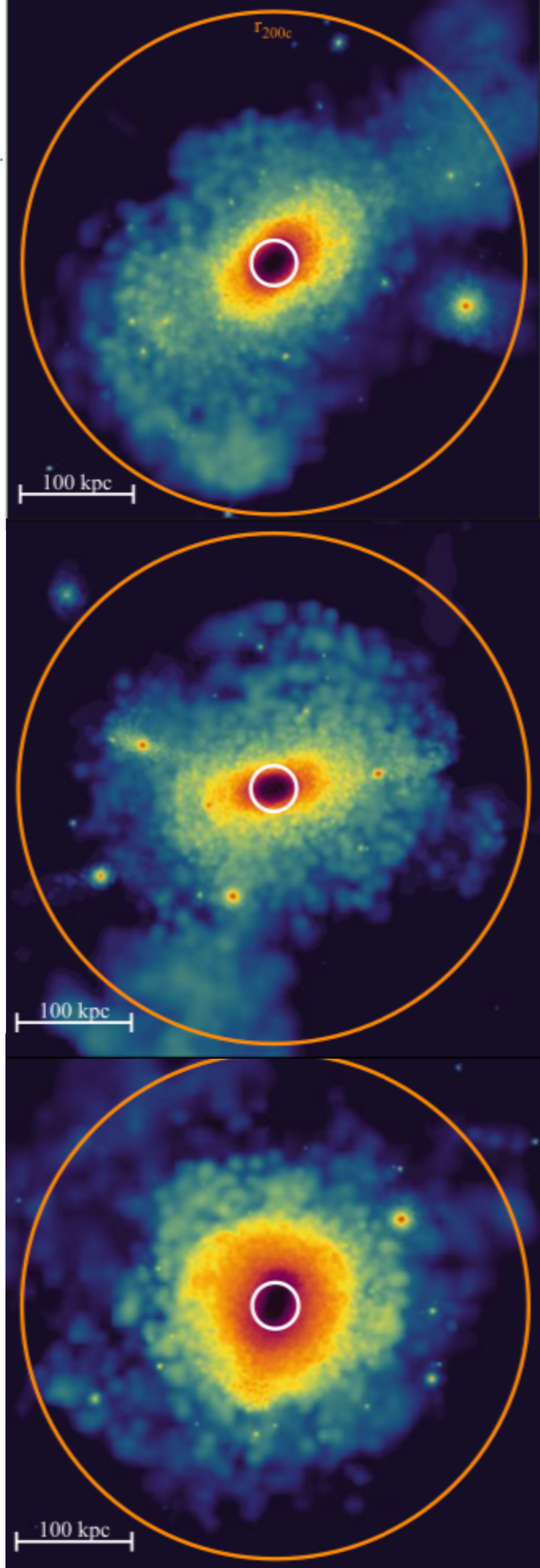
- Now: SAGA Geha+2017, Mao+2021; Stellar Streams Legacy Survey Martinez-Delgado+2021; LIGHTS Trujillo+2021; MADCASH Carlin+2016,2021; LBT-SONG Davis+2020, Garling+2021; Dwarfs gobbling dwarfs Martinez-Delgado+2021;

- **Coming: A low-surface brightness discovery space with Euclid, the Vera Rubin Observatory, and the Nancy Grace Roman Space Telescope**

Variant with major mergers at earlier times

Original halo

Variant with major mergers at later times



Rey & Starkenburg 2022

MERGER HISTORIES AND THE DIVERSITY OF STELLAR HALOS

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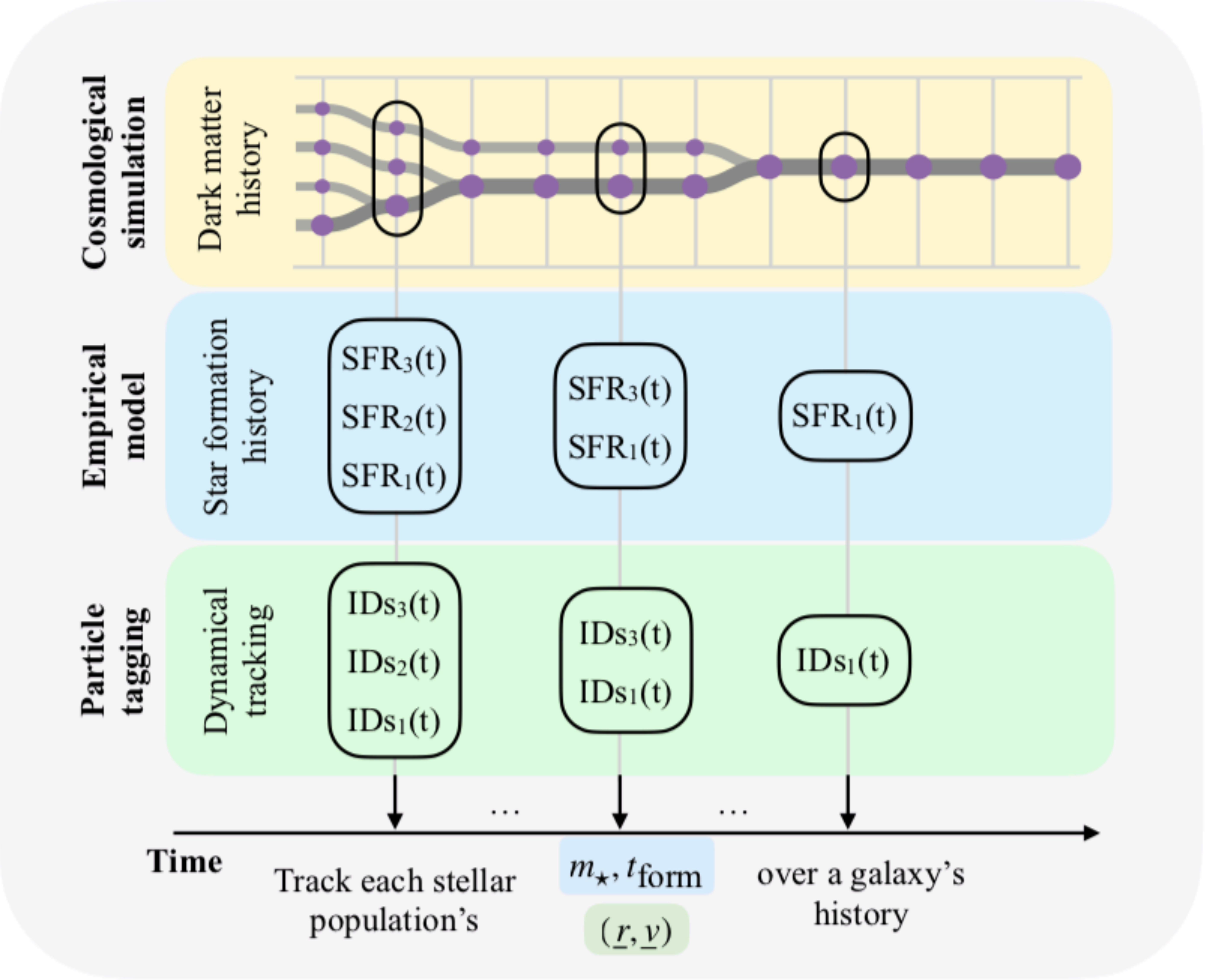
- Genetic modifications of merger histories to create small specific variations
- For dark matter-only zoom simulations of Milky Way-mass halos
- With star formation histories from empirical galaxy formation model
- And repeated particle tagging along a galaxy's evolution

➡ **Cleanly separate effects from merger histories and star formation histories**



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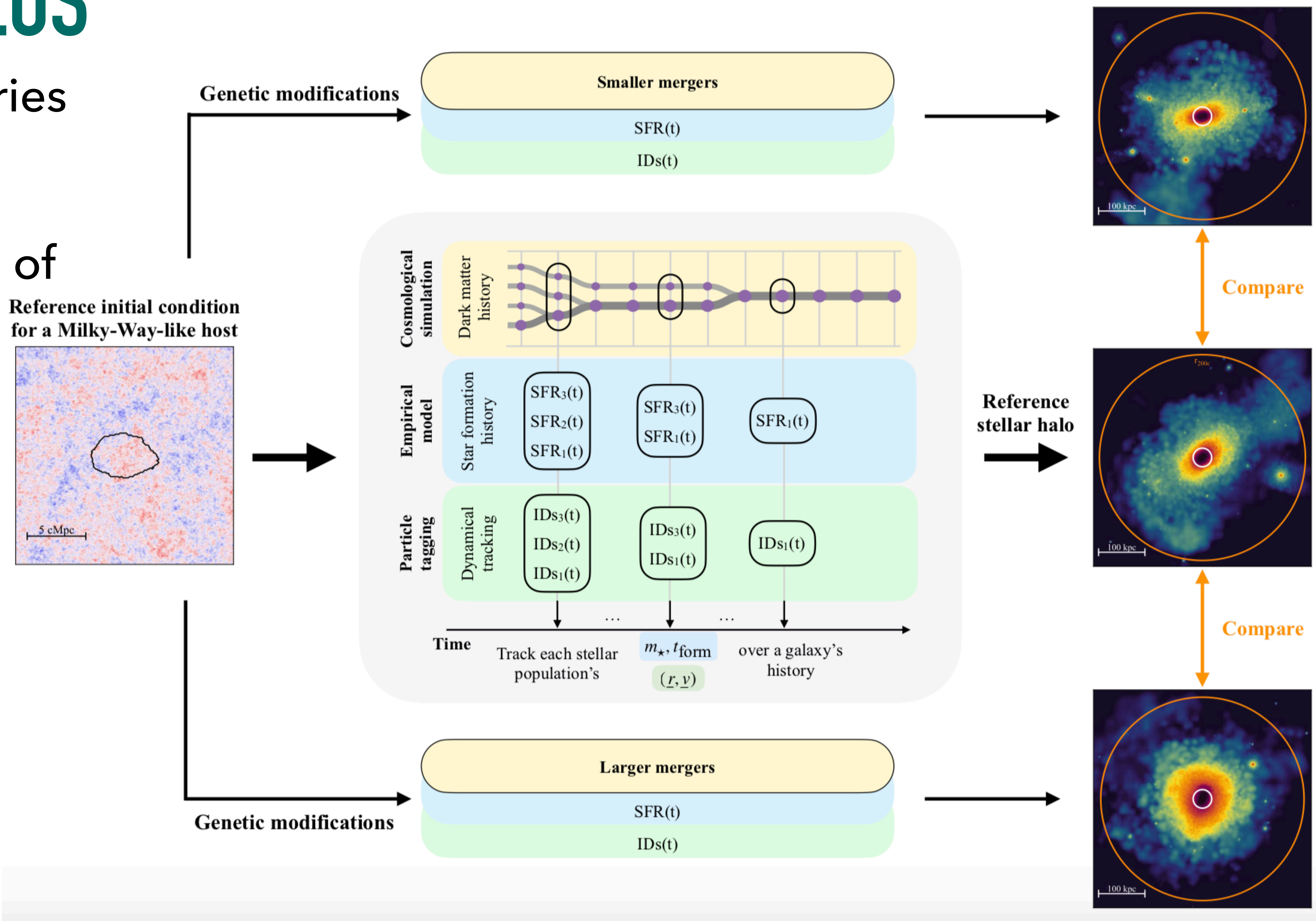


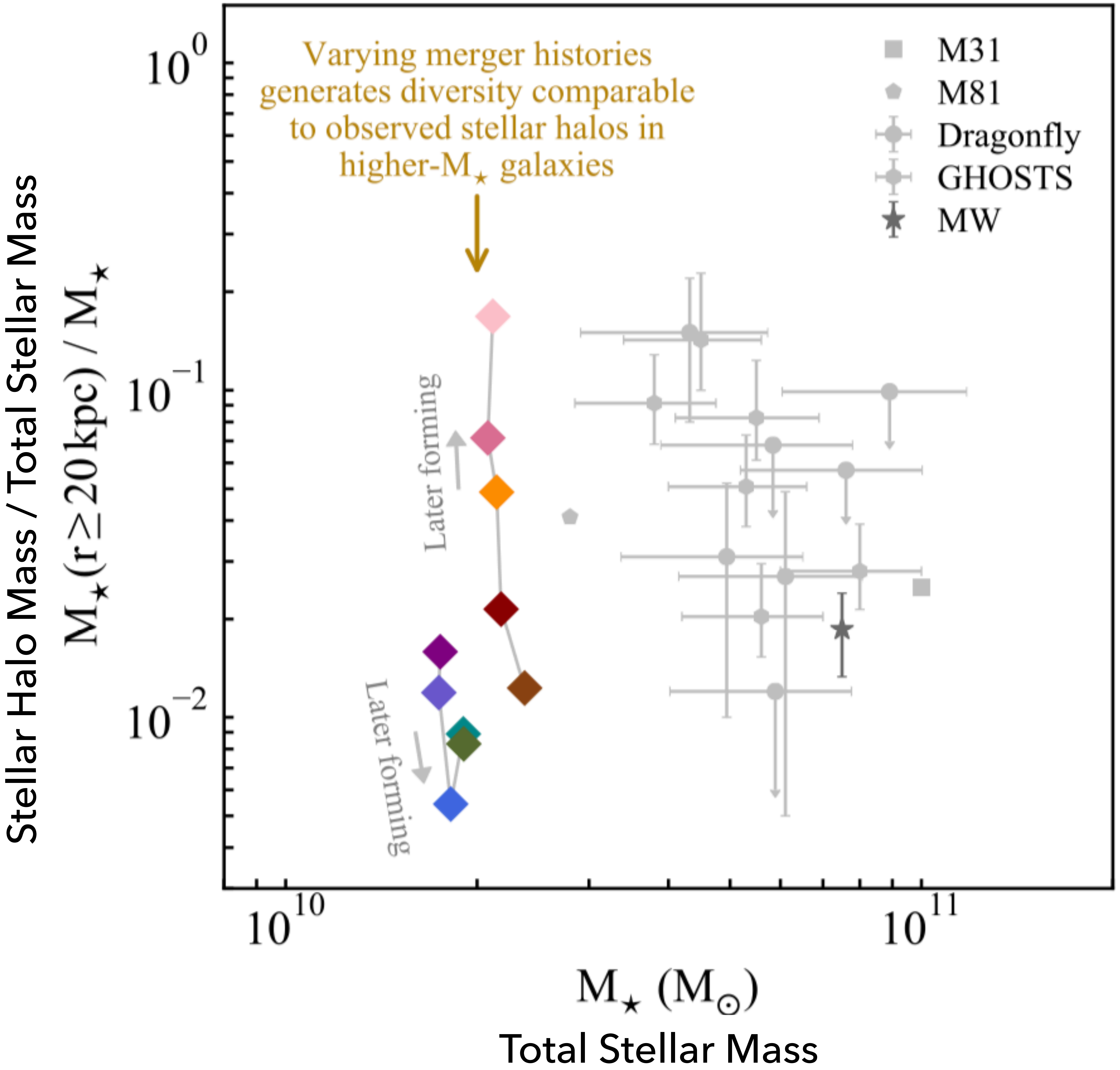
MERGER HISTORIES AND THE DIVERSITY OF STELLAR HALOS

- Observationally there is a huge diversity in stellar halo masses at fixed total stellar mass (~1.5dex) (Monachesi et al. 2016; Merritt et al. 2016; Courteau et al. 2011; Deason et al. 2019; Smercina et al. 2020)

- **Just small variations in two sets of merger histories span almost all of the observed range,** mostly caused by late violent mergers than bring in-situ stars out in the halo

- Dependence of the diversity (spread) on the low-mass end slope of the Stellar mass-Halo mass relation

Rey & Starkenburg 2022



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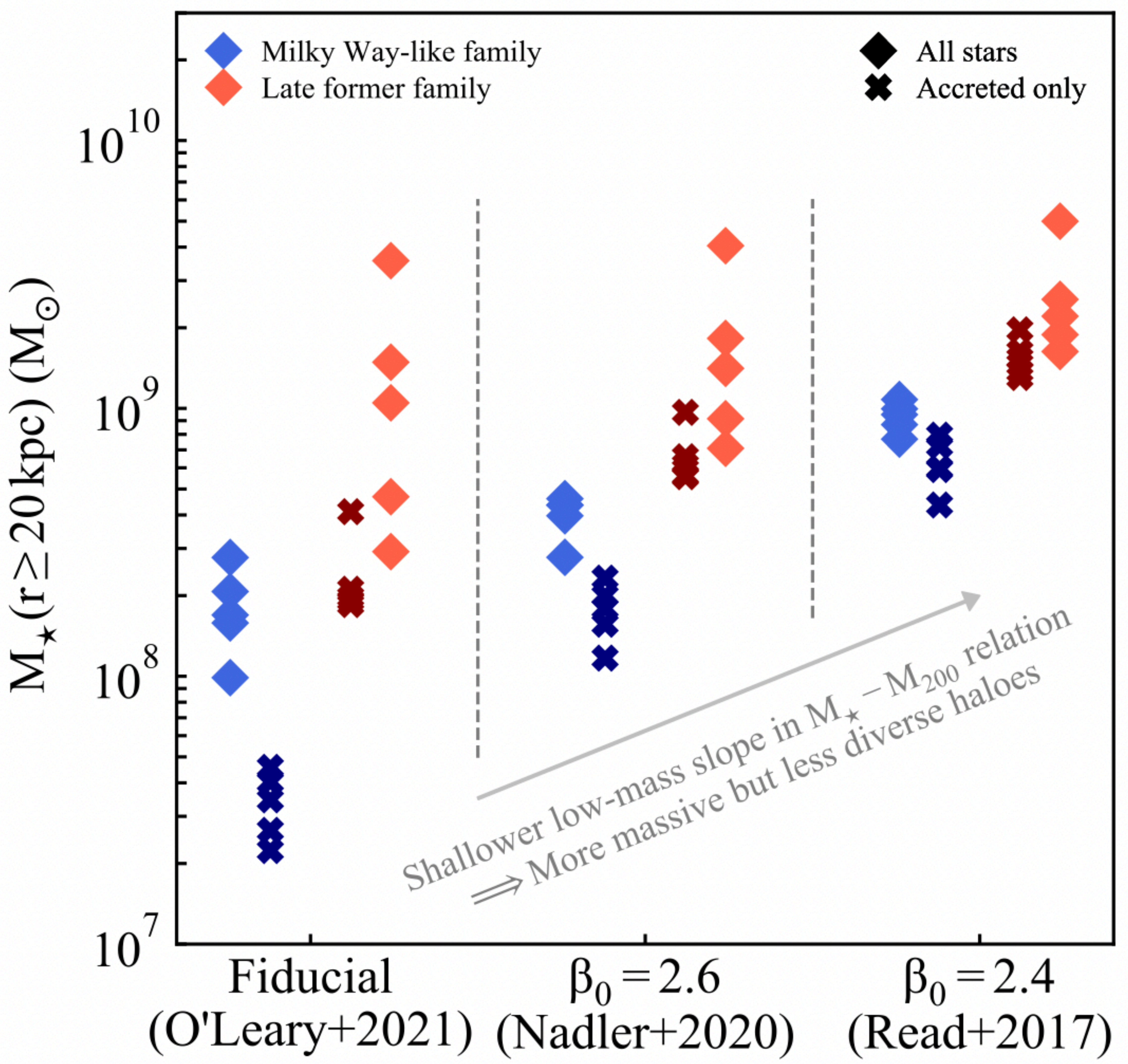
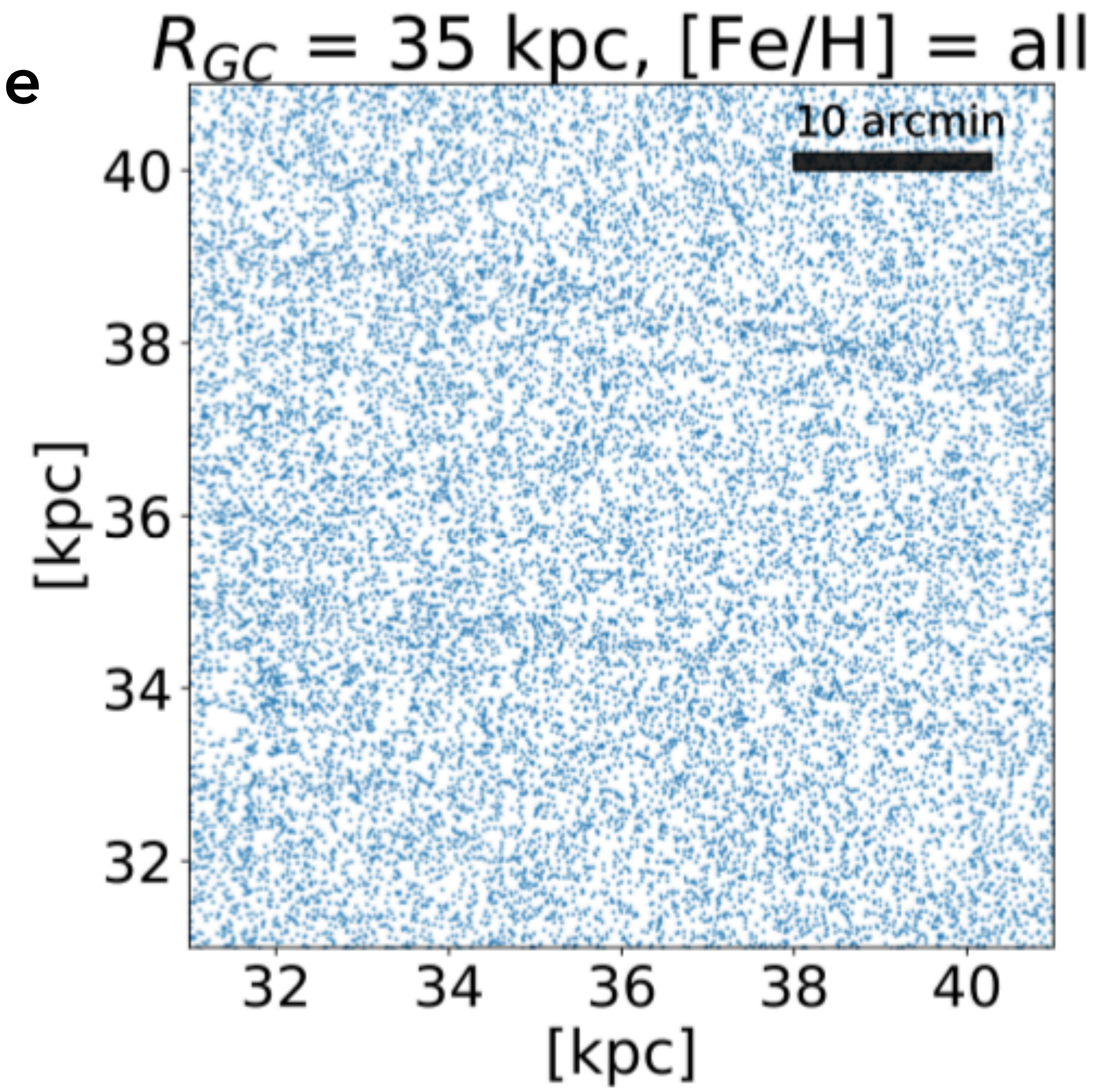


STELLAR STREAMS IN EXTERNAL GALAXIES

COLD STREAMS IN EXTERNAL GALAXIES WITH ROMAN

- **A low-surface brightness discovery space for Euclid, the Vera Rubin Observatory, and the Nancy Grace Roman Space Telescope**
  - Inserting globular cluster streams in PAndaS M31 fields (McConnachie et al. 2018)
  - Most massive streams would have been possible to see in PAndaS data



Pearson, **Starkenburg**+2019:
Mock streams in M31 with Roman.

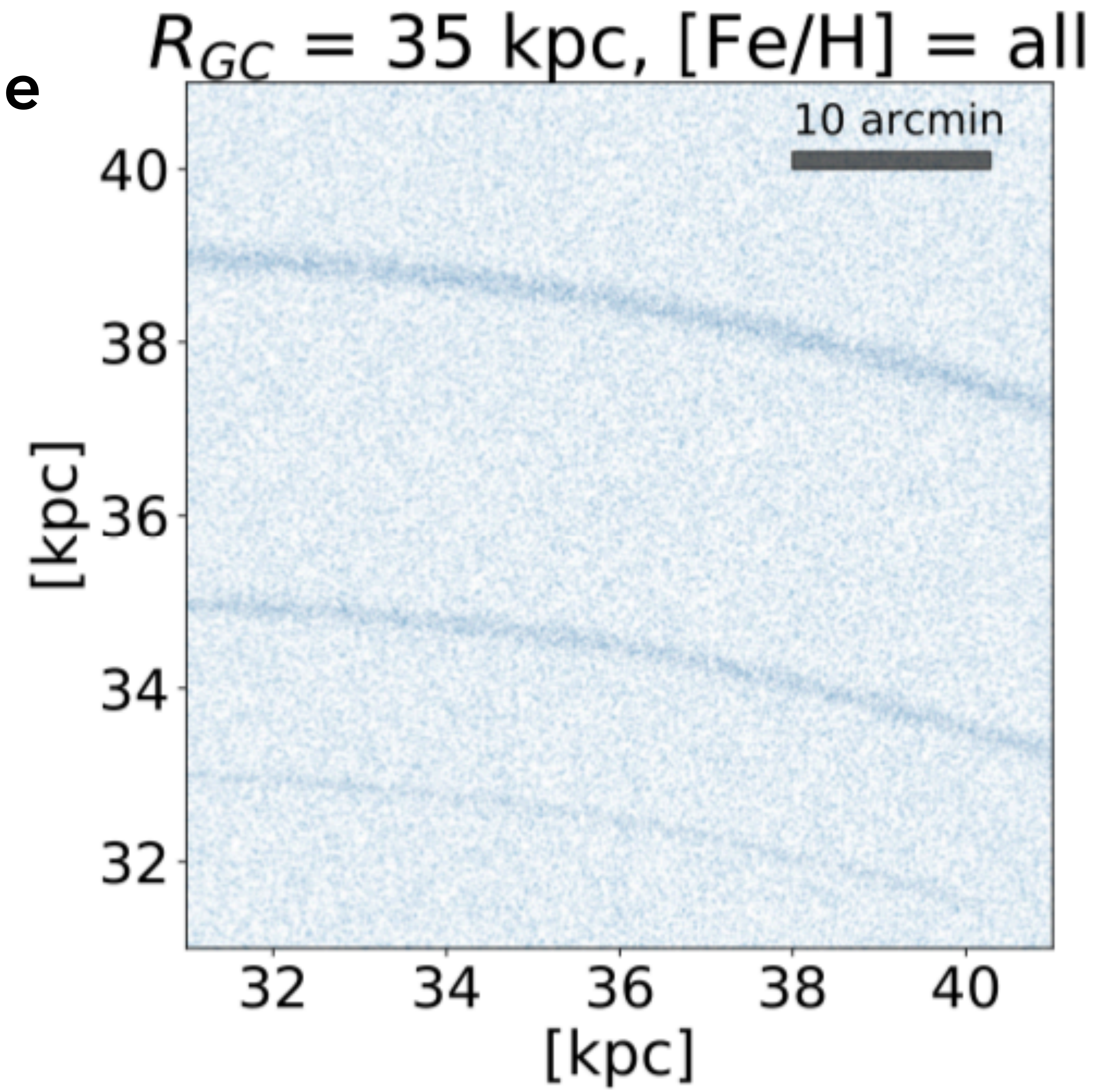
COLD STREAMS IN EXTERNAL GALAXIES WITH ROMAN

- **A low-surface brightness discovery space for Euclid, the Vera Rubin Observatory, and the Nancy Grace Roman Space Telescope**

- Inserting globular cluster streams in PAndaS M31 fields (McConnachie et al. 2018)

- The Roman Telescope will resolve all streams

- This is true out to 3.5 Mpc, a volume that contains ~200, mostly lower-mass galaxies



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Mock streams in M31 with Roman.

PREDICTING TIDAL DEBRIS AROUND LMC–SIZED GALAXIES

T. **Starkenburg**, Pearson et al. in prep.

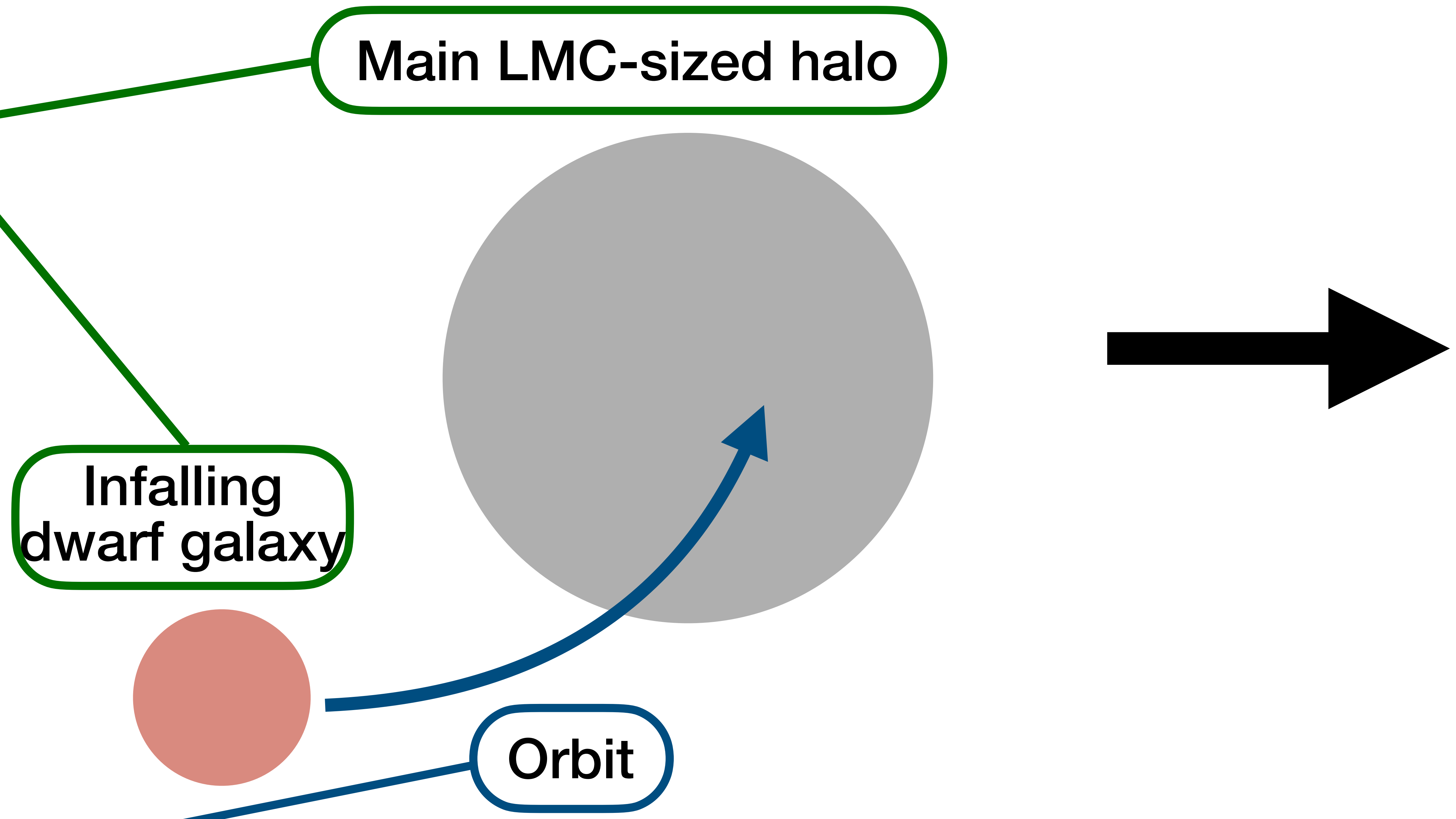
Input from the Santa Cruz Semi-Analytic Model *(Somerville+2008,2012)*:

- Infall time for all accreted dwarf galaxies
- Evolution of the main halo
- Properties of accreted dwarf galaxies at infall

+

Input from orbit distributions in cosmological N-body simulations *(Wetzel+2011)*:

- Sample pericenter radii and orbital circularity of satellites at infall



PREDICTING TIDAL DEBRIS AROUND LMC-SIZED GALAXIES

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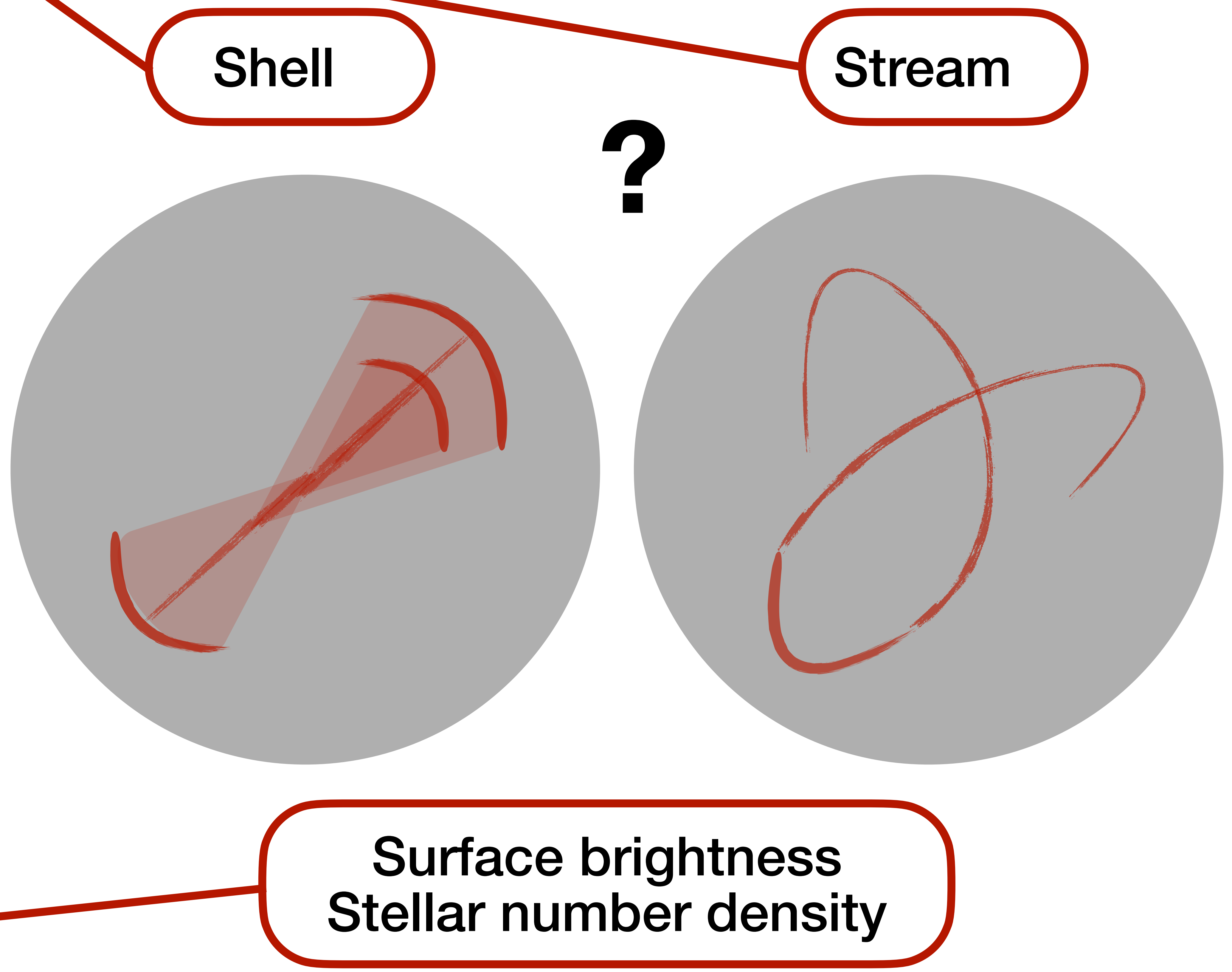
Predict debris Morphology and Observability:

- Estimate dark matter halo stripping timescale using mass loss semi-analytic model SatGen *(Jiang+2021; Green+2022)*
- Estimate lifetime of the tidal debris until phase-mixed
- **Predict debris morphology for each subsequent orbit**
- **Predict surface brightness and stellar density** *(Johnston 2001; Hendel & Johnston 2015)*



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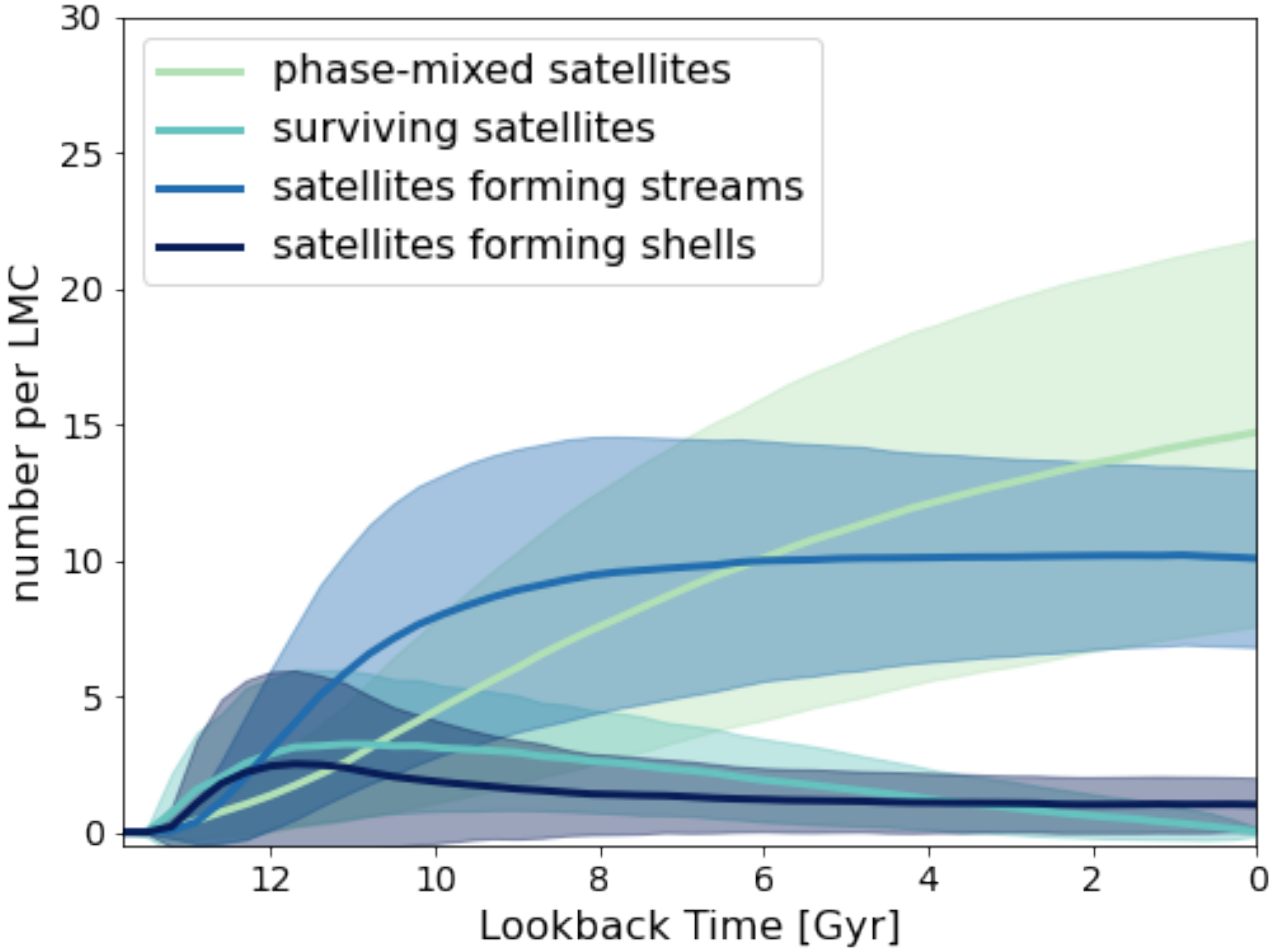

- Generate accretion histories for *many* isolated halos
- Use our (arbitrarily) large sample size to provide robust predictions and test the effects of models, assumptions and input parameters
  - **Nearby galaxies will have tidal features (streams)**

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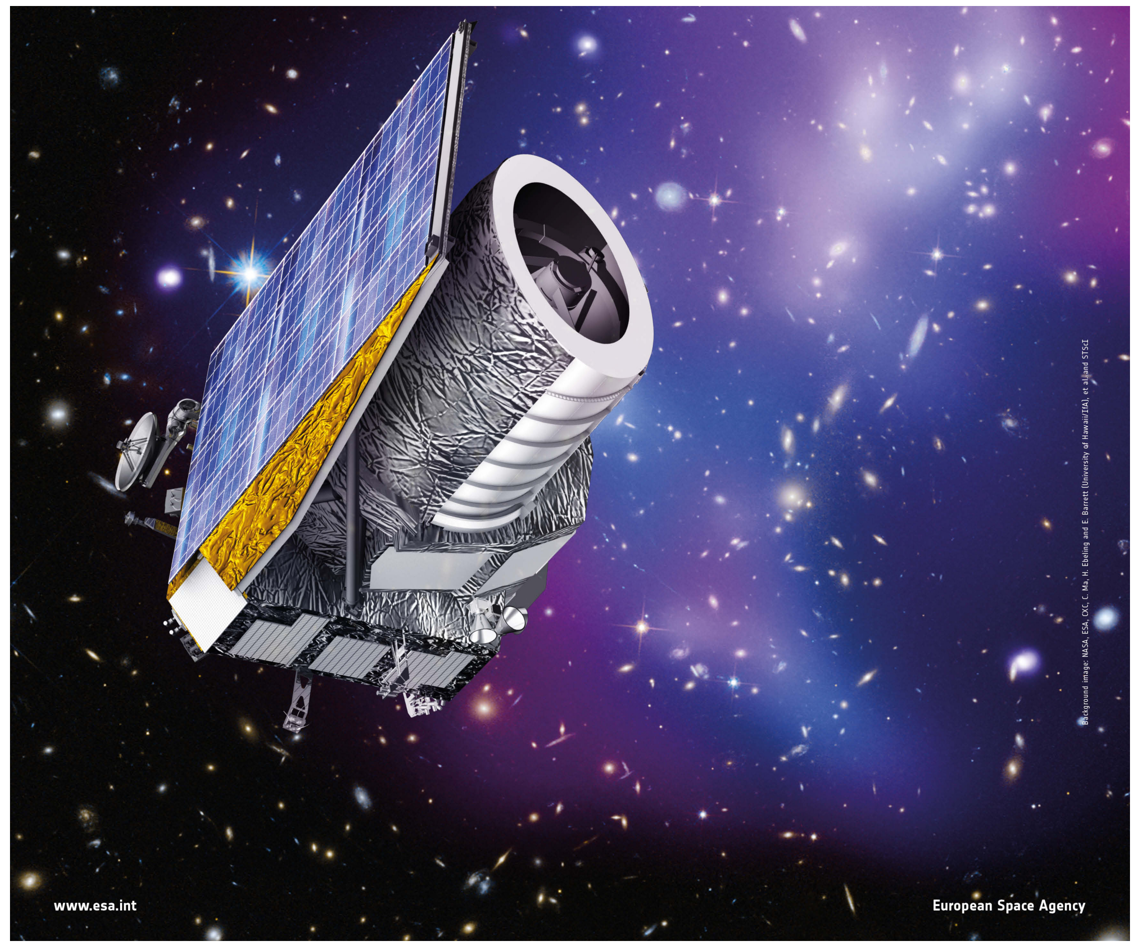
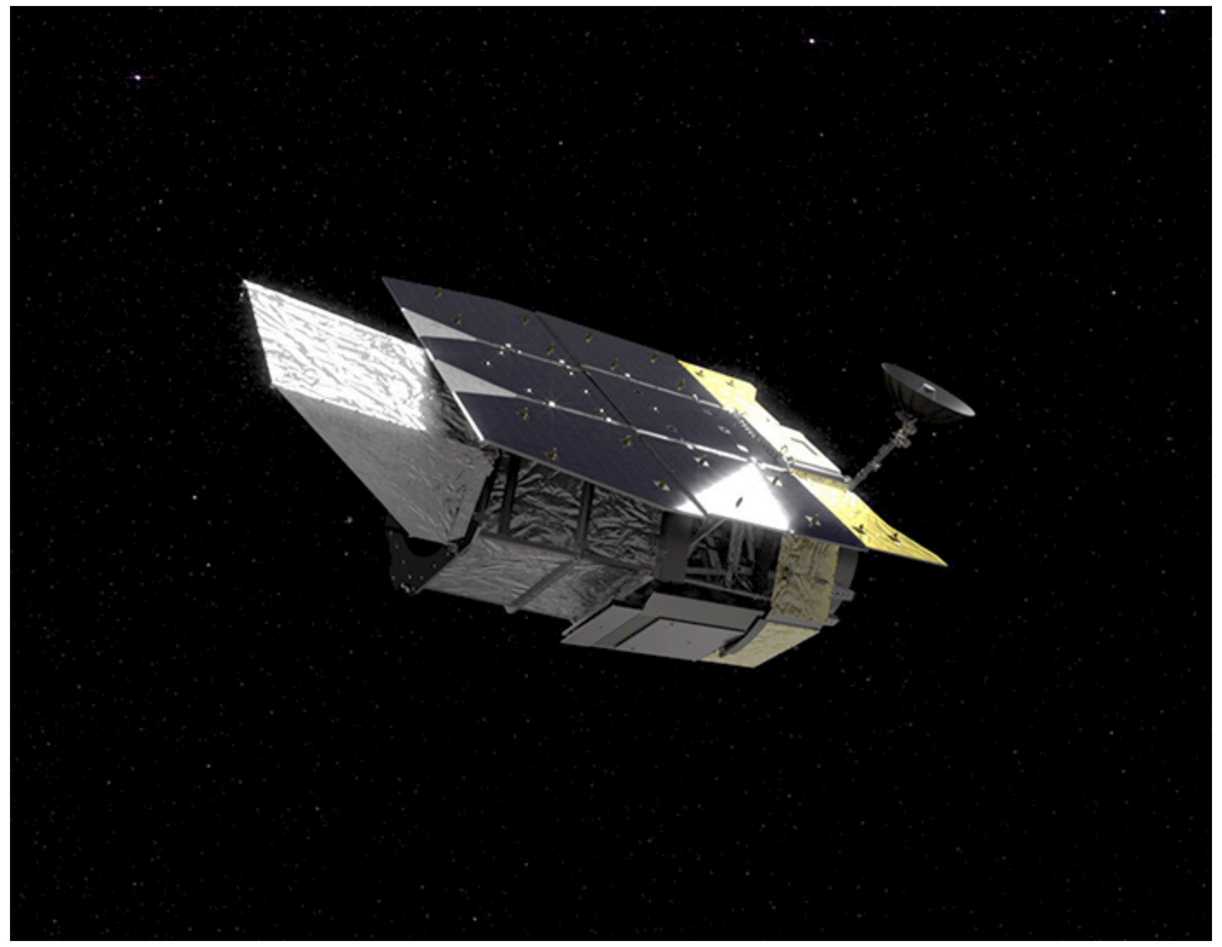
Fraction of galaxies

Euclid



Rubin / LSST

Roman



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PREDICTING TIDAL DEBRIS AROUND LMC-SIZED GALAXIES

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- Generate accretion histories for *many* isolated halos
- Use our (arbitrarily) large sample size to provide robust predictions and test the effects of models, assumptions and input parameters
  - **Nearby galaxies will have visible tidal features with Euclid, Roman, and Rubin**
  - These are challenging to detect (sky subtraction & masks, galactic cirrus, …) -> work in progress in collaborations

PREDICTING TIDAL DEBRIS AROUND LMC–SIZED GALAXIES

T. **Starkenburg**, Pearson et al. in prep.

- Generate accretion histories for *many* isolated halos
- Use our (arbitrarily) large sample size to provide robust predictions and test the effects of models, assumptions and input parameters
  - **Nearby galaxies will have visible tidal features with Euclid, Roman, and Rubin**
  - **Statistics will provide constraints on galaxy formation! Here: very steep low-mass stellar mass-halo mass relation**

CONCLUSIONS

- Stellar halos are affected by their *full* merger histories as well as low-mass galaxy formation, and can provide constraints on these

  (Rey & T. Starkenburg 2022)

- Most galaxies (including dwarfs!) will have stellar streams and satellites in their halo, and statistics on these can provide novel constraints on galaxy formation models

  (T. Starkenburg, Pearson et al. in prep.)

- Upcoming facilities (Euclid, Roman, Rubin) will be able to observe large (?) samples of tidal features in nearby galaxies

  (Pearson, T. Starkenburg et al. 2019)
  (T. Starkenburg, Pearson et al. in prep.)