Understanding the effects of mergers on Milky Way-mass galaxies

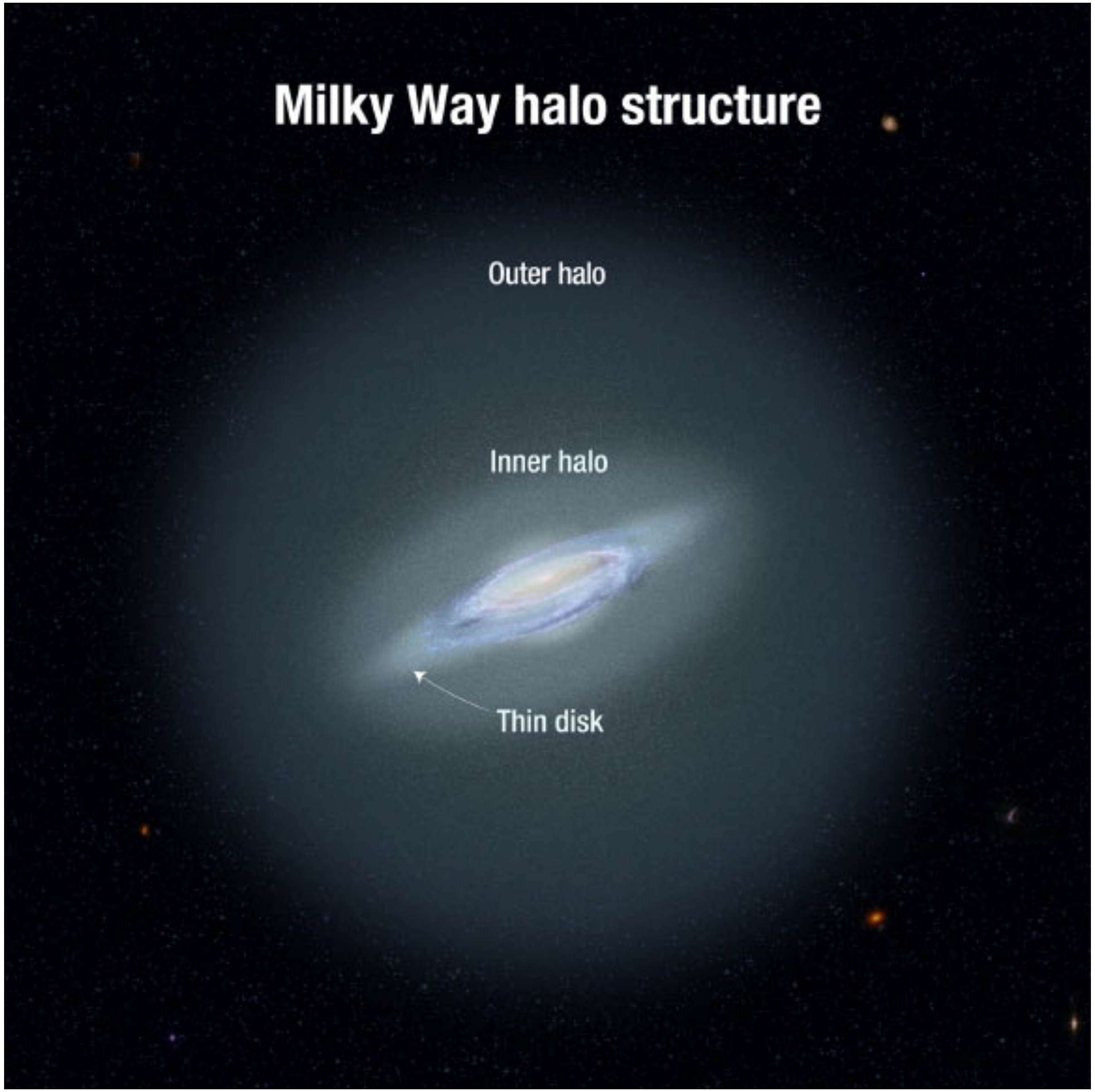
Linking the Galactic accretion history with the extra-galactic.

Richard D'Souza, Vatican Observatory.

With Eric Bell, Adam Smercina, Roelef de Jong, Antonella Monachesi, Katya Gozman

How much do mergers affect the properties of galaxies?

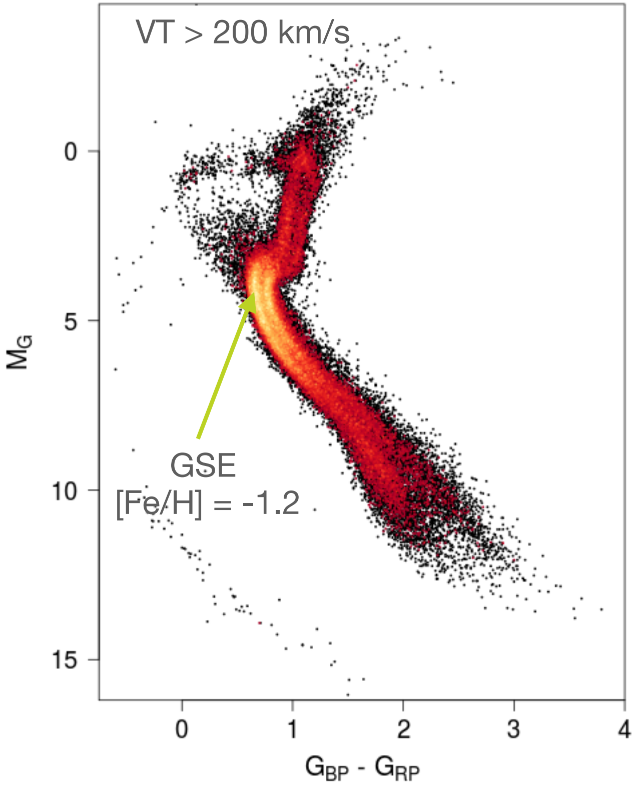
x 100 factor in stellar mass
in every column


Milky Way halo structure
Outer halo
Inner halo
Thin disk

The accretion history of the MW

GSE

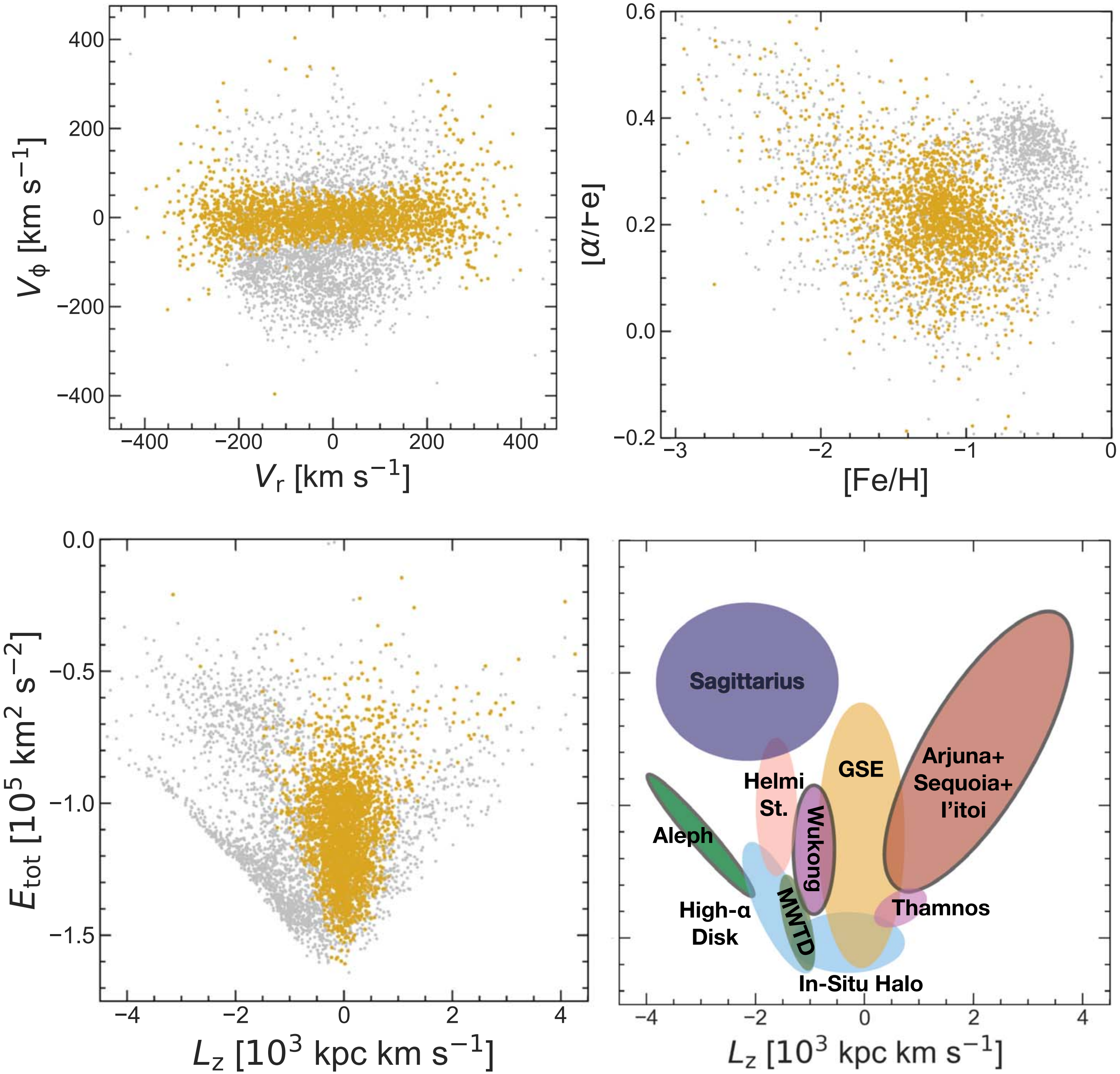
- Mass
- Metallicity
- Time of Merger



Gaia Collaboration et al. 2018

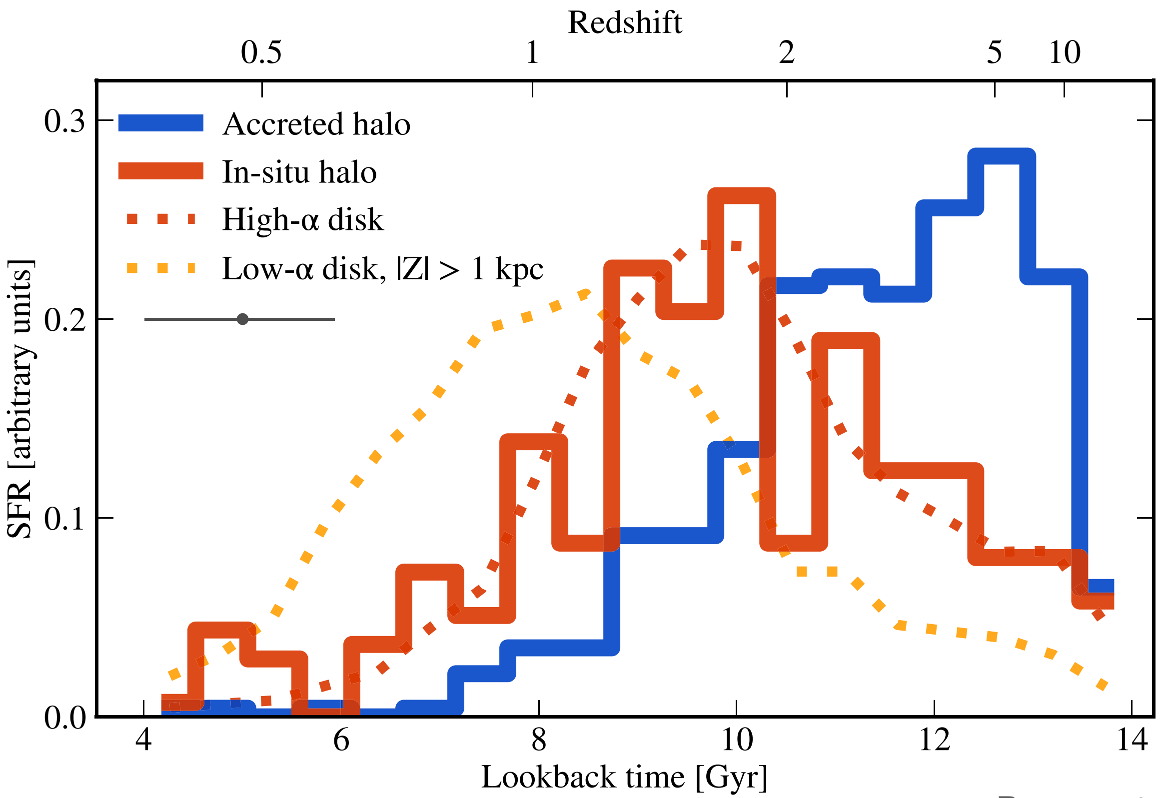
H3 Survey

Naidu et al. 2020



The accretion history of the MW

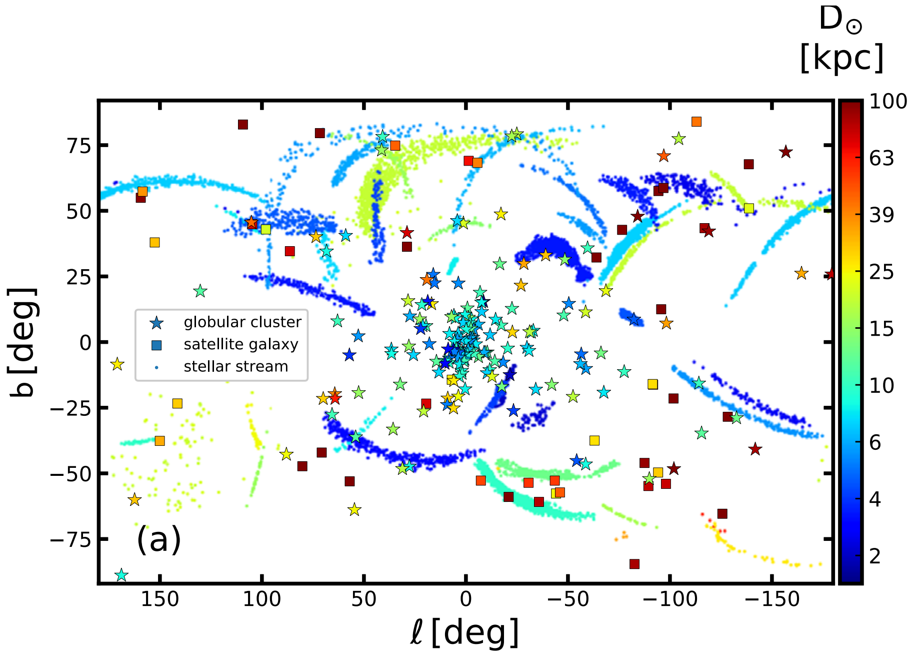
Timing the merger GSE



Bonaca et al. 2020

The accretion history of the MW

Other tracers: GCs, Streams, Satellite Galaxies



Malhan et al. 2022

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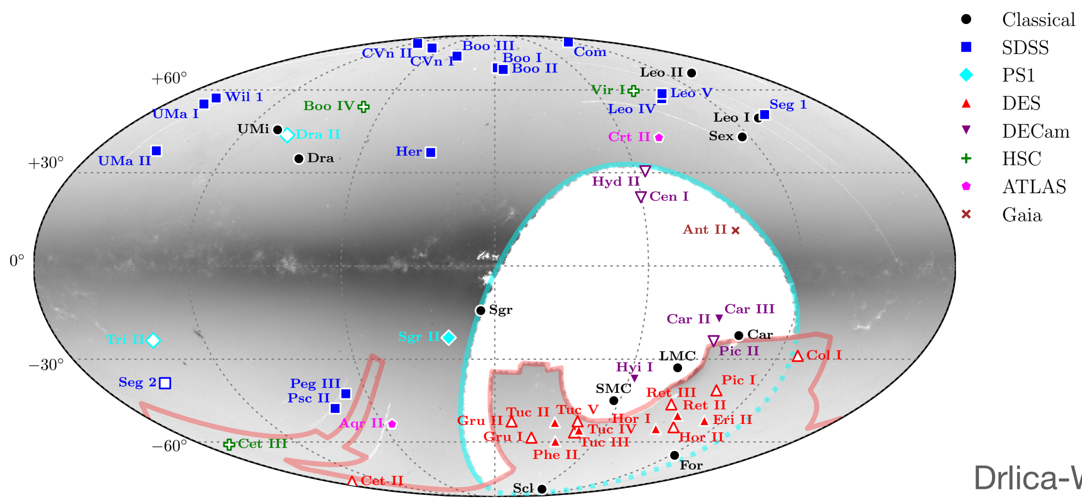
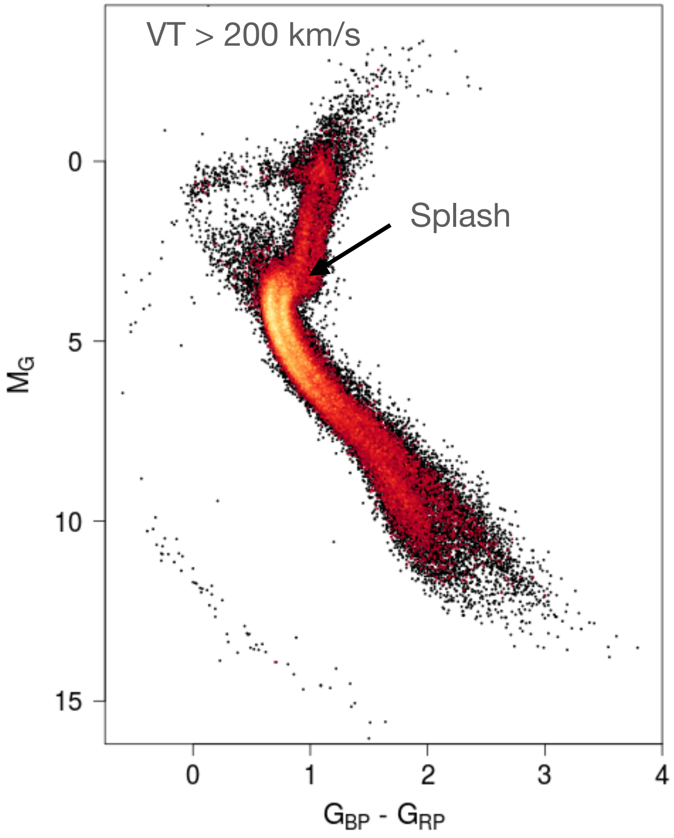


Drlica-Wagner et al. 2020

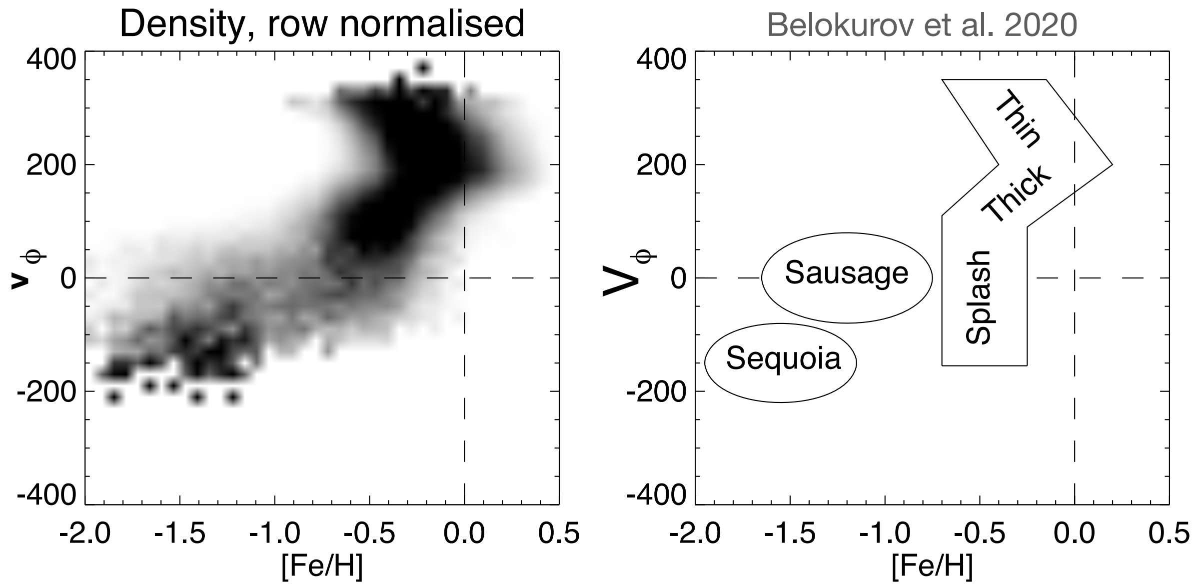
Consequences of accretions on MW

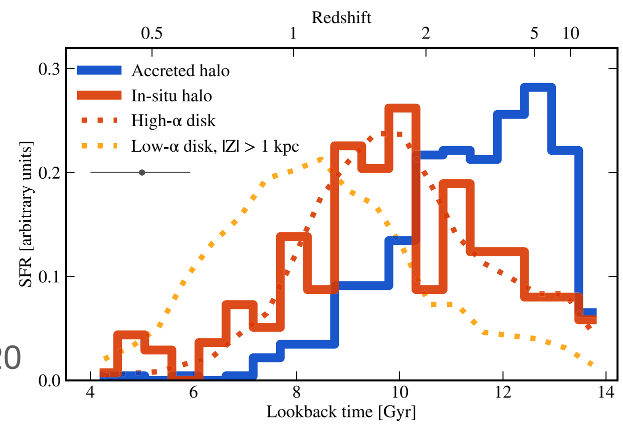
The biggest Splash: due to GSE



Gaia Collaboration et al. 2018

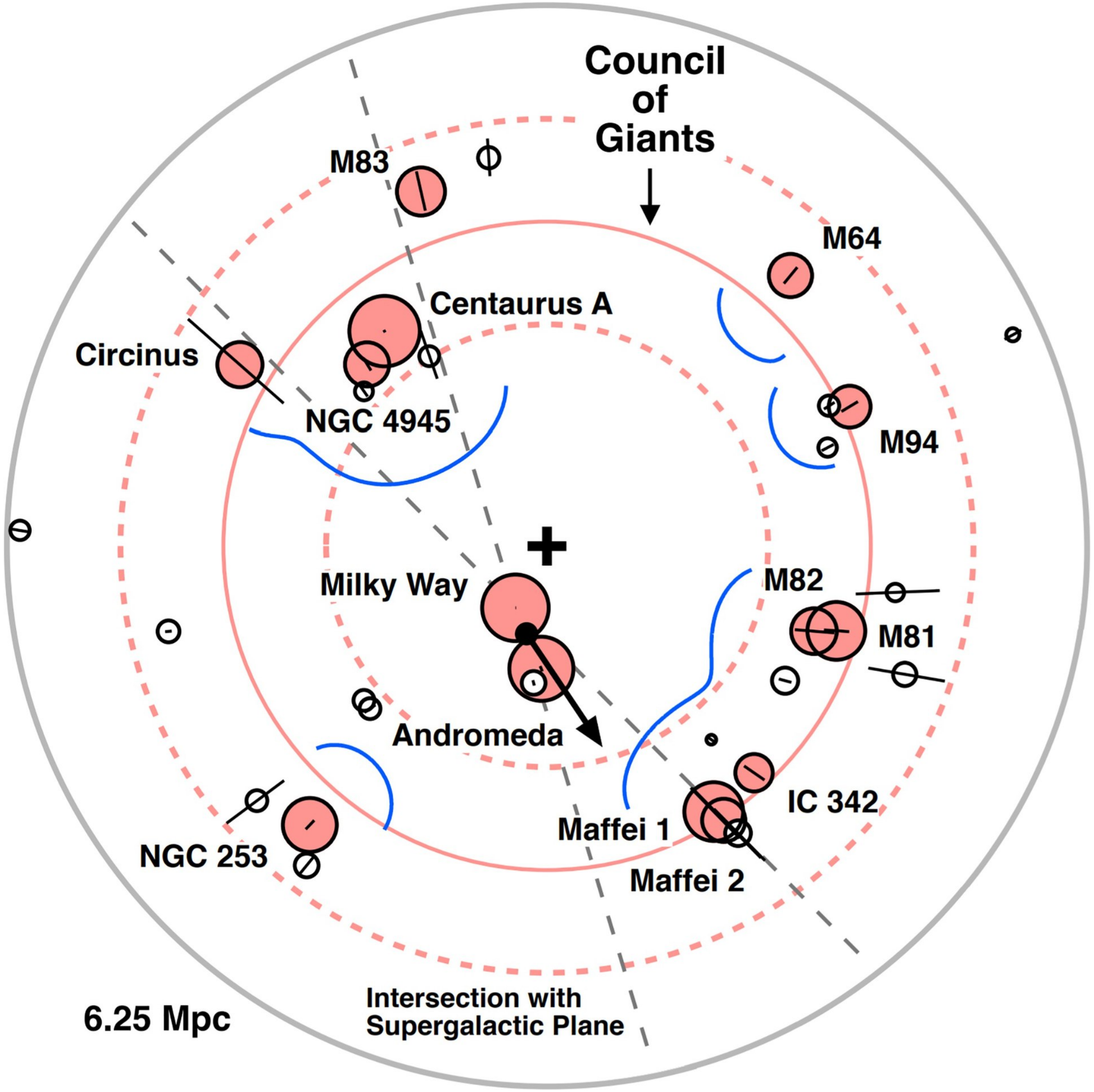
Gallart et al. 2019





Bonaca et al. 2020

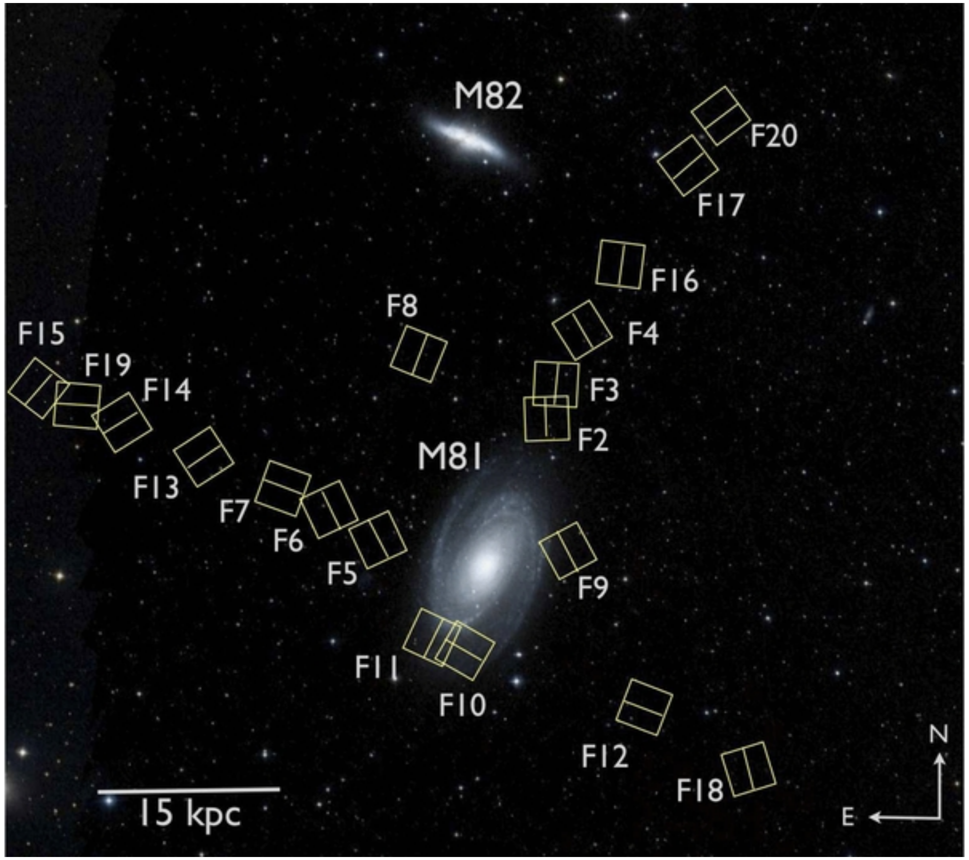
How do we compare with other MW galaxies in the Local Volume?



- Out to ~11 Mpc
- Structure: S4G
- ISM and star formation: SINGS, THINGS, PHANGS, LEGUS
- Can be studied by HST/JWST/Roman and Subaru/Rubin Observatory.

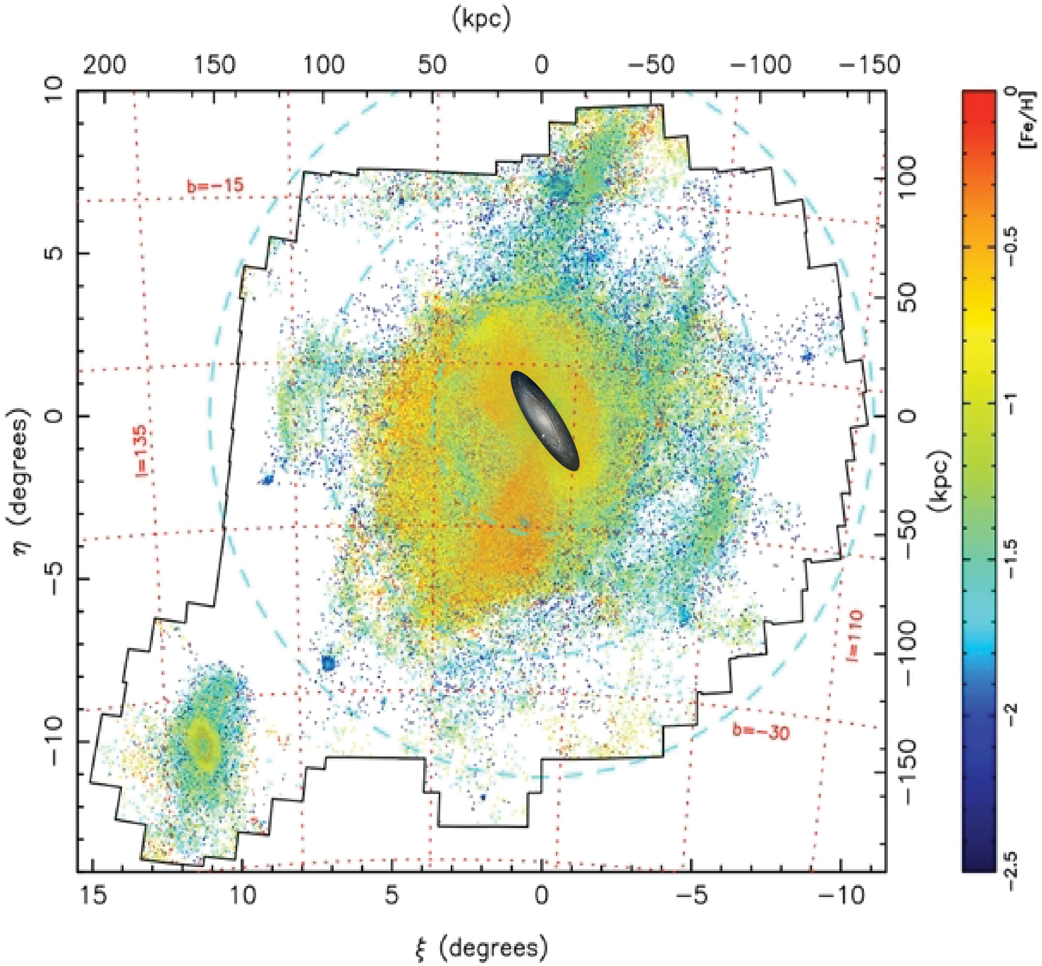
Studying the stellar halos of nearby MW-mass galaxies through resolved stars

Pencil Beams with HST



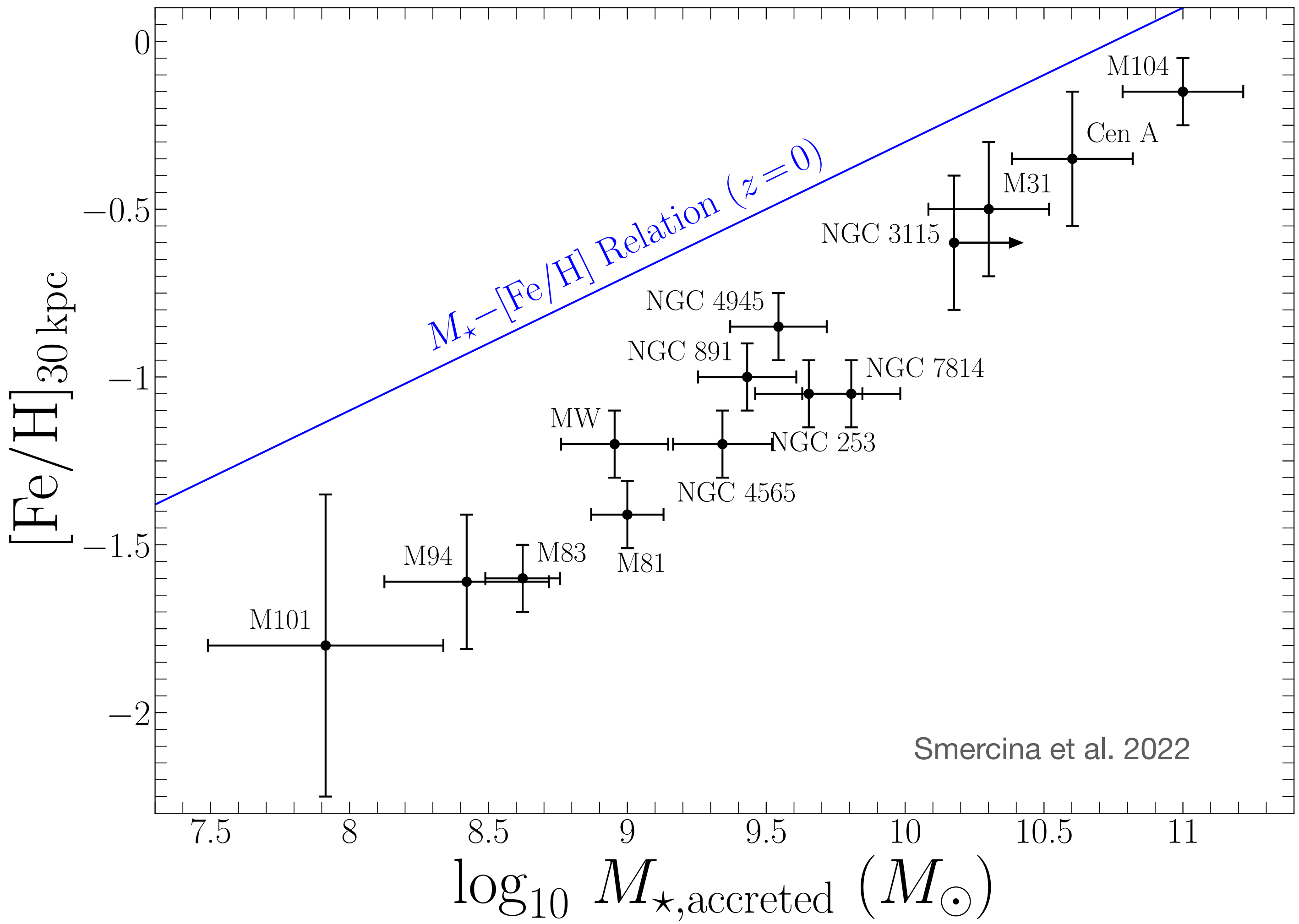
GHOSTS: Monachesi et al. 2013

Wide-field ground-based surveys



PAndAS Survey: Ibata et al. 2014

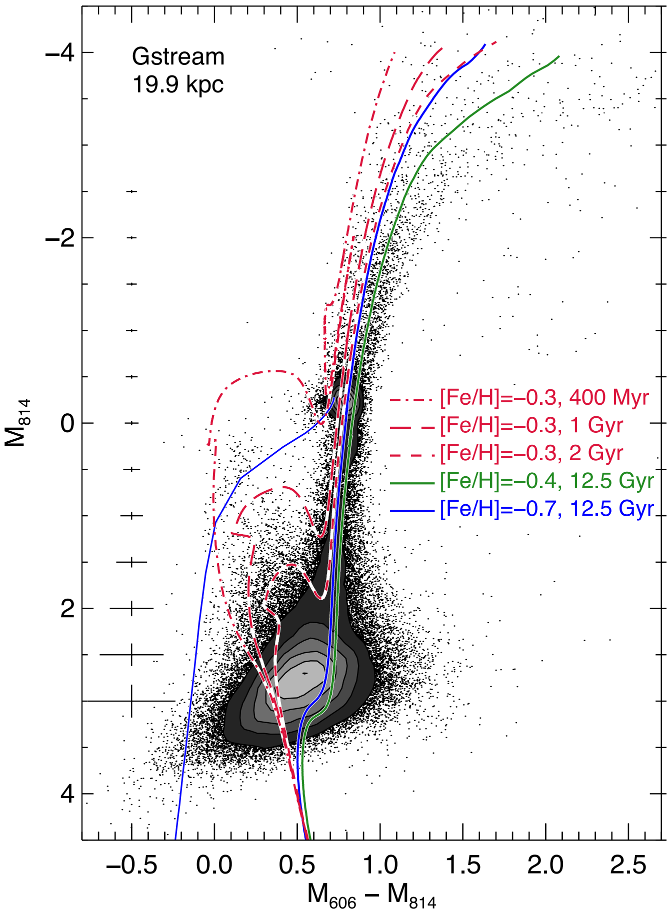
Stellar halo metallicity-mass relationship

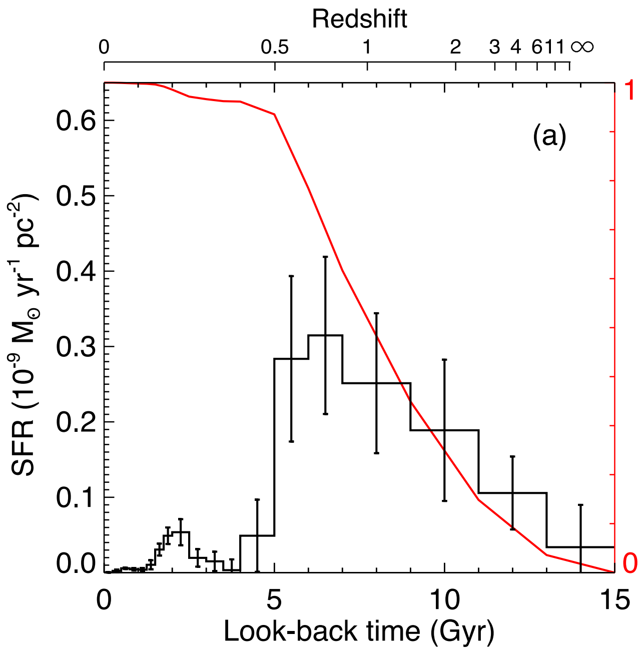


Harmsen et al. 2017
D’Souza et al. 2018

Age of the stellar halo-I

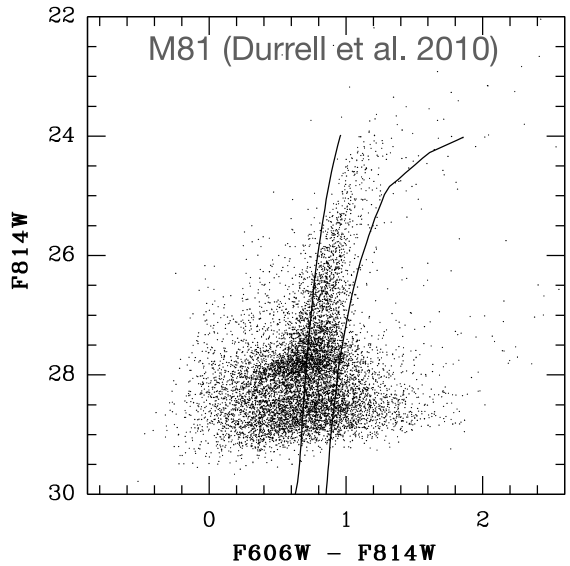
Giant Stream in M31 ~1 Mpc

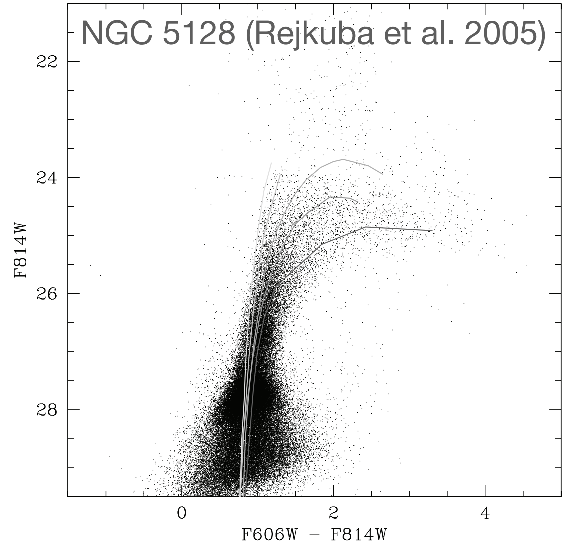




Bernard et al. 2015

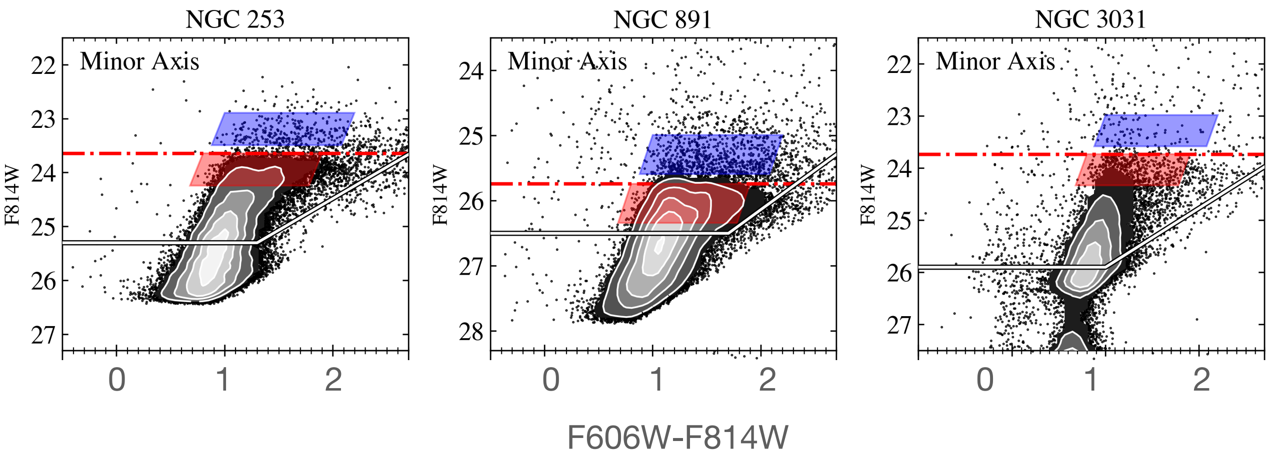
~3.5 Mpc



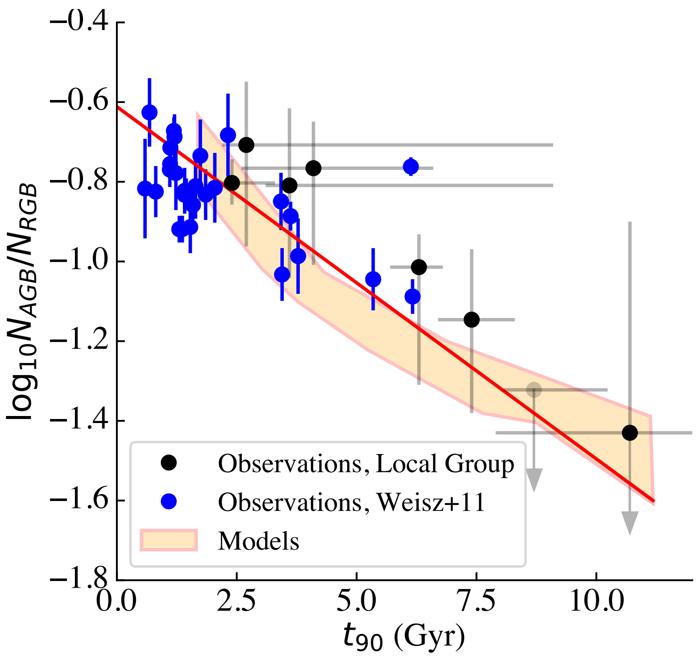


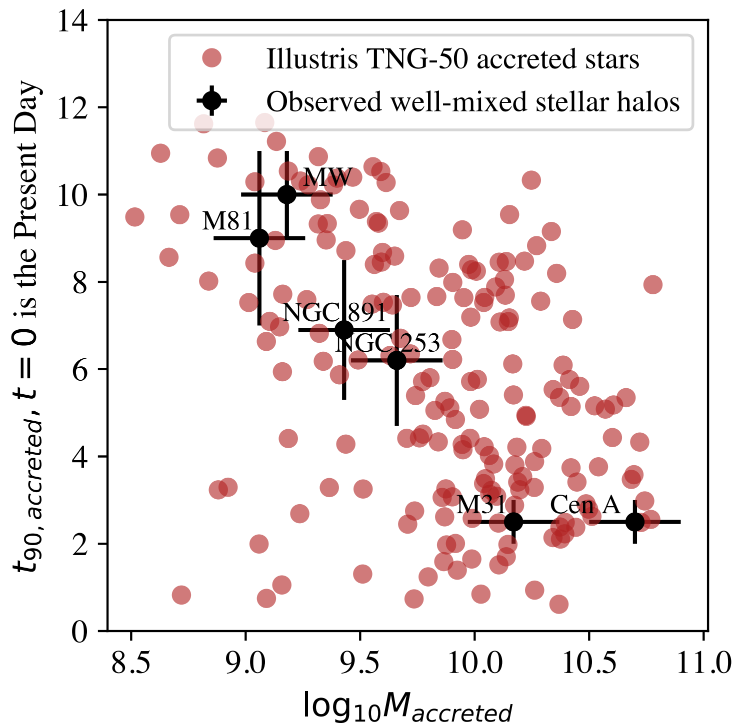
Age of the stellar haloes-II

AGB/RGB ratios



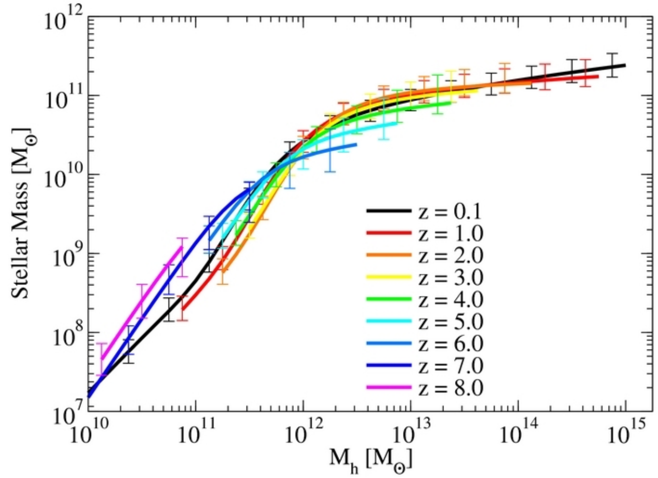
Harmsen et al. 2023
(In preparation)





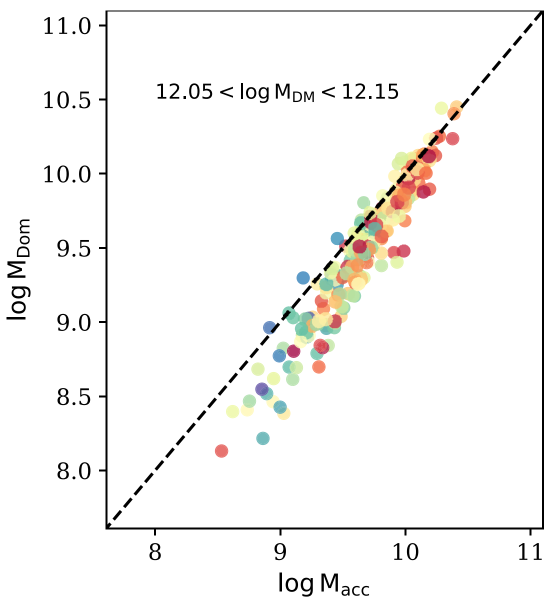
Cosmological Models-I

Models articulated in
Deason et al. 2016
D'Souza et al. 2018a
Monachesi et al. 2019



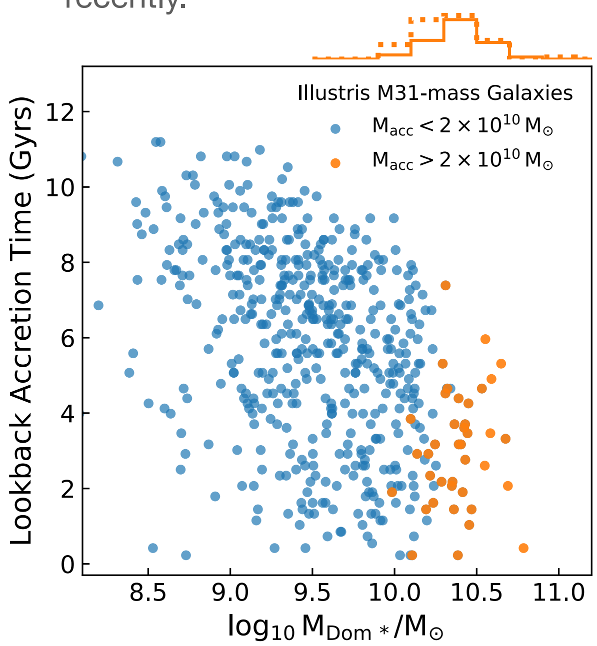
Behroozi et al. 2013

The mass of the largest progenitor can be constrained from the mass of the stellar halo.



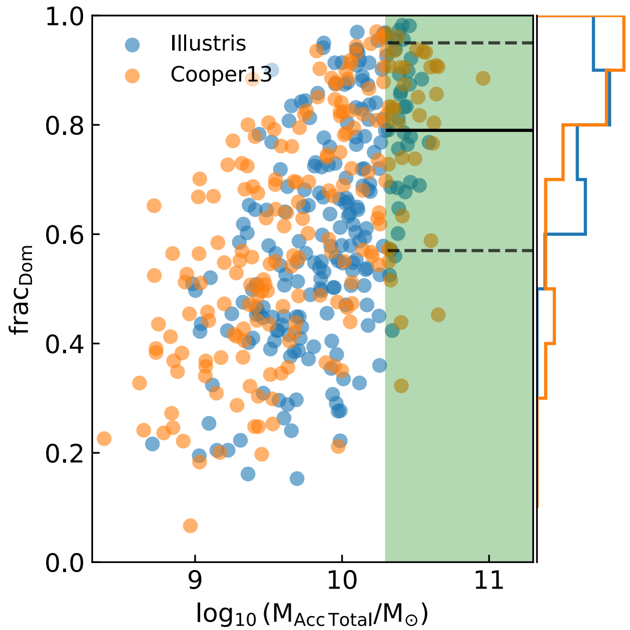
D'Souza et al. 2018a

Larger progenitors are accreted recently.



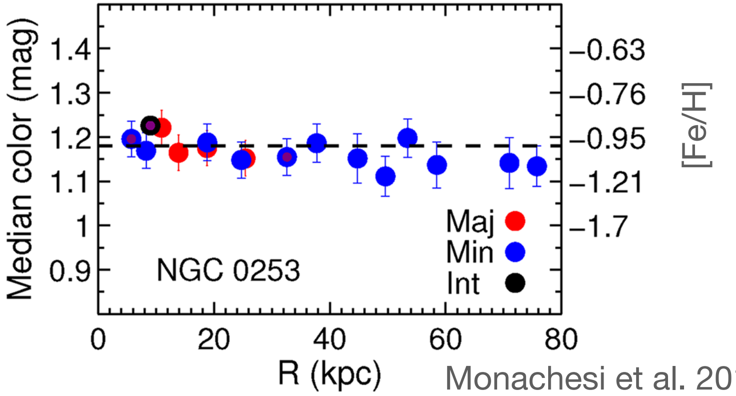
D'Souza et al. 2018b

Larger stellar halos are built predominately from one large progenitor.

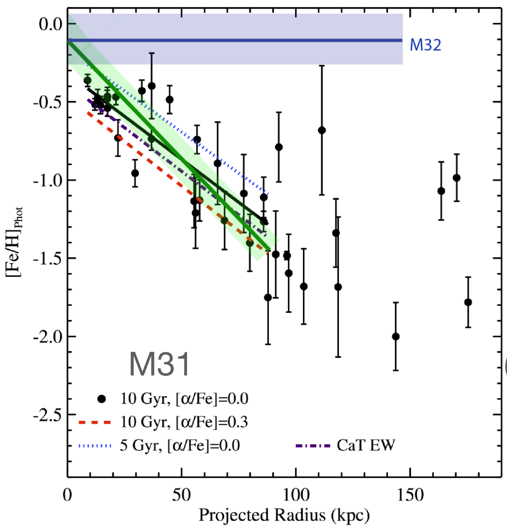


D'Souza et al. 2018b

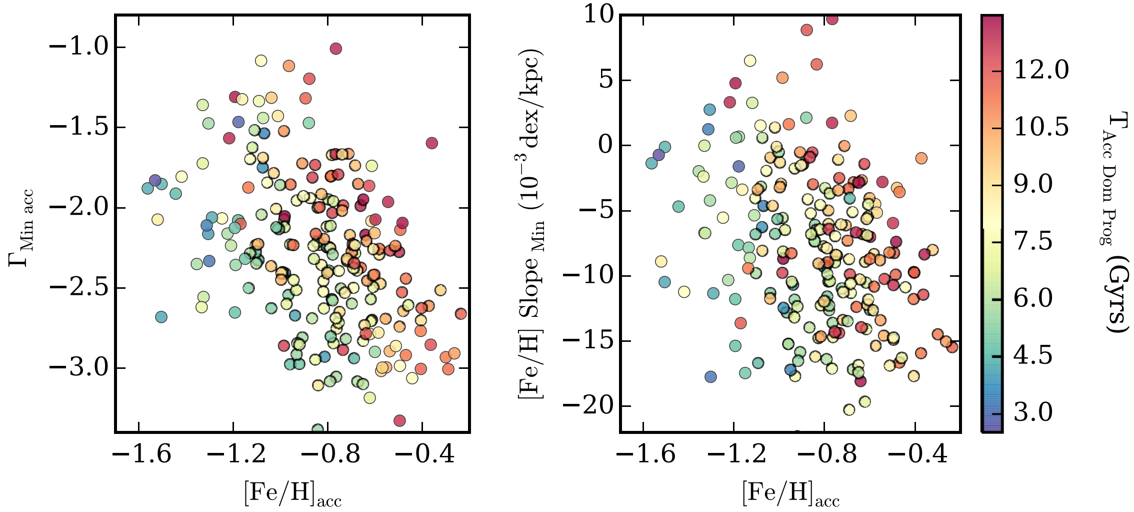
Cosmological models-II
Profiles and Gradients



Monachesi et al. 2016

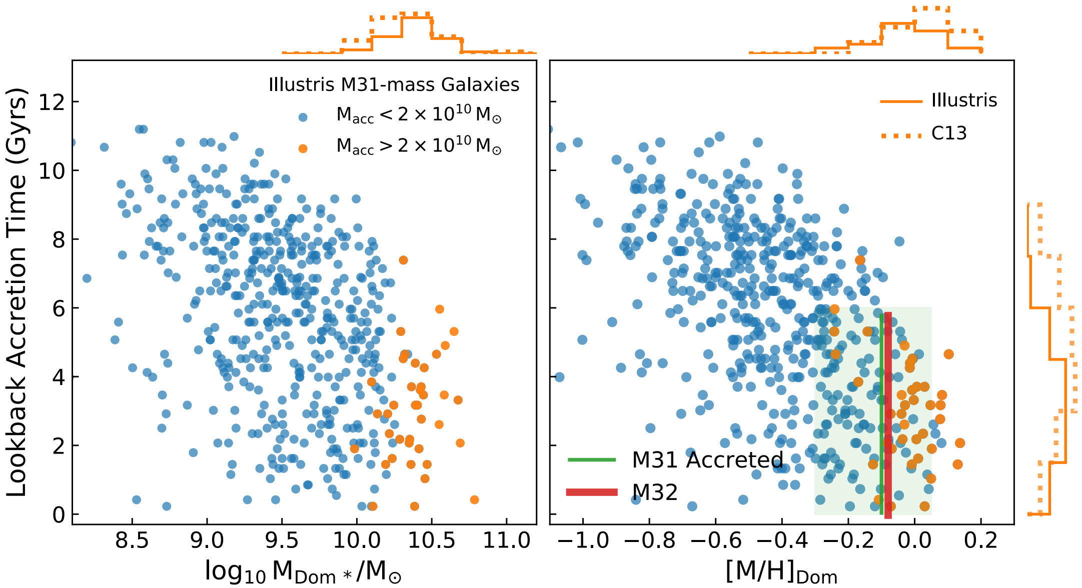


SPLASH Survey (Gilbert et al. 2014)

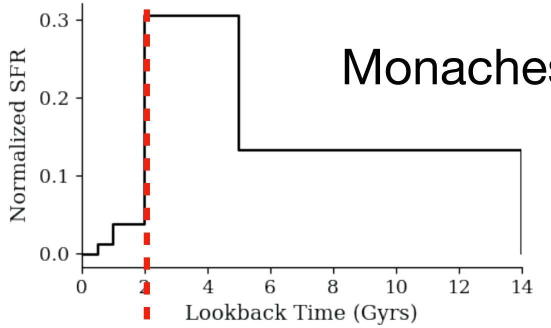


D'Souza et al. 2018
Monachesi et al. 2019

Deciphering M31's merger - I

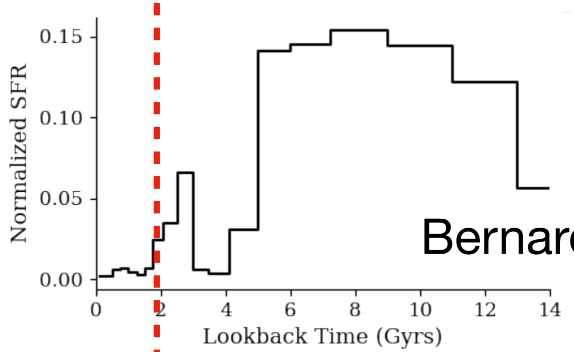


1. M32 [Fe/H] ~ -0.1



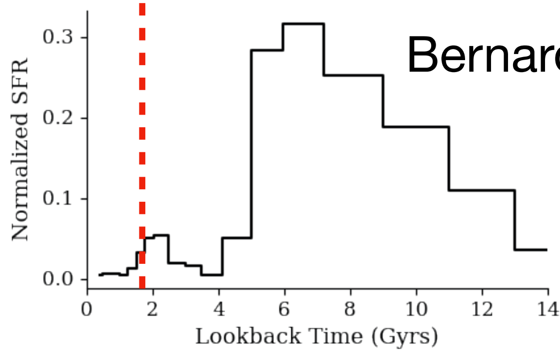
Monachesi et al. 2012

2. Inner Spheroid [Fe/H] ~ -0.5

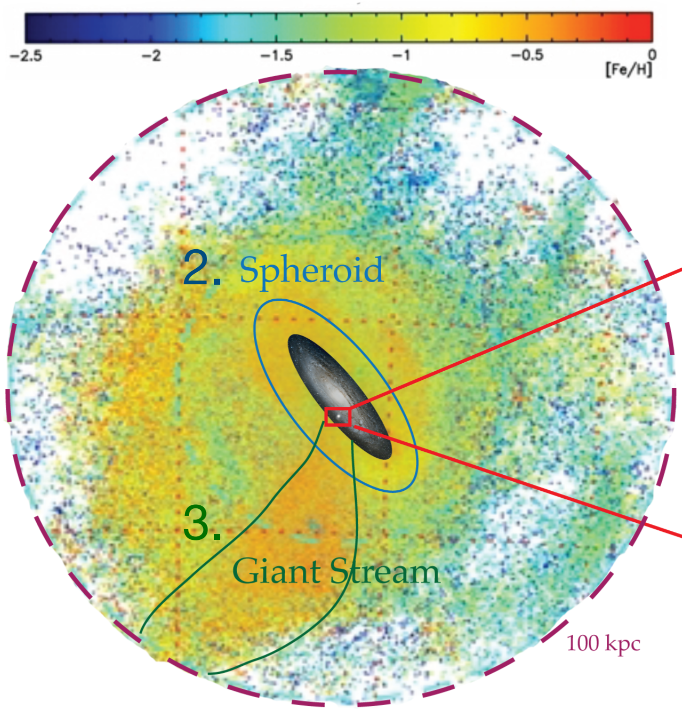


Bernard et al. 2015

3. Giant Stream [Fe/H] ~ -0.3



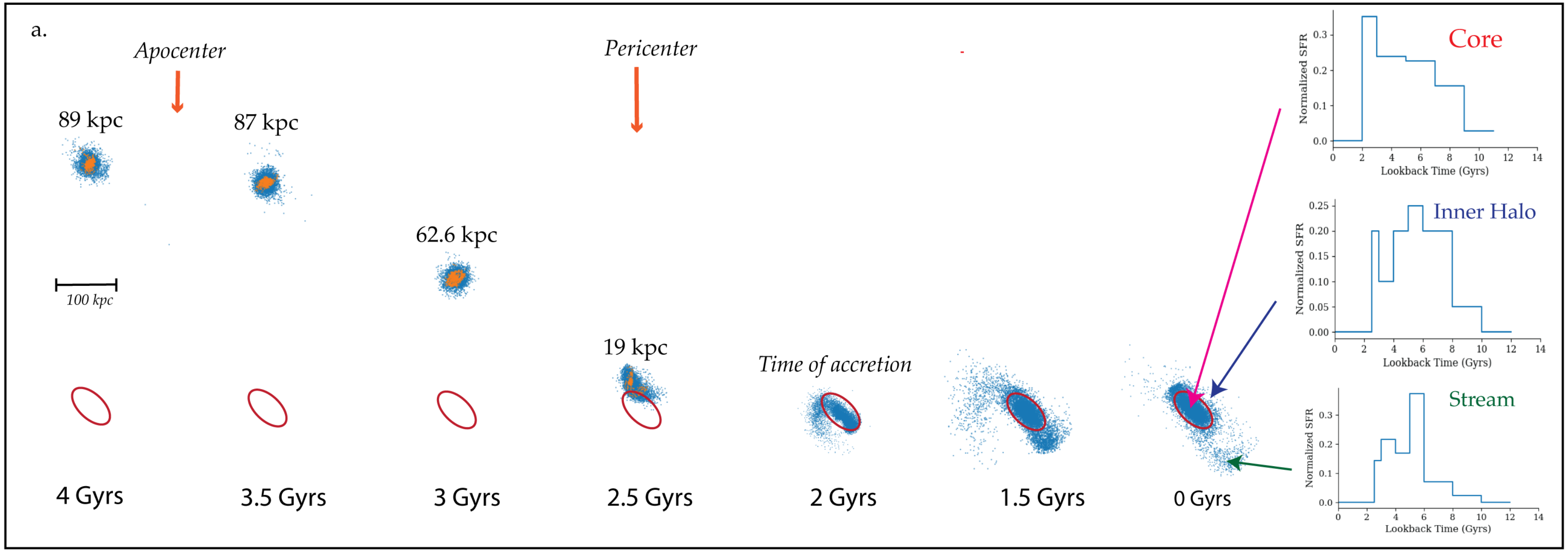
Bernard et al. 2015



1. M32

D'Souza et al. 2018b

Deciphering M31's merger-II

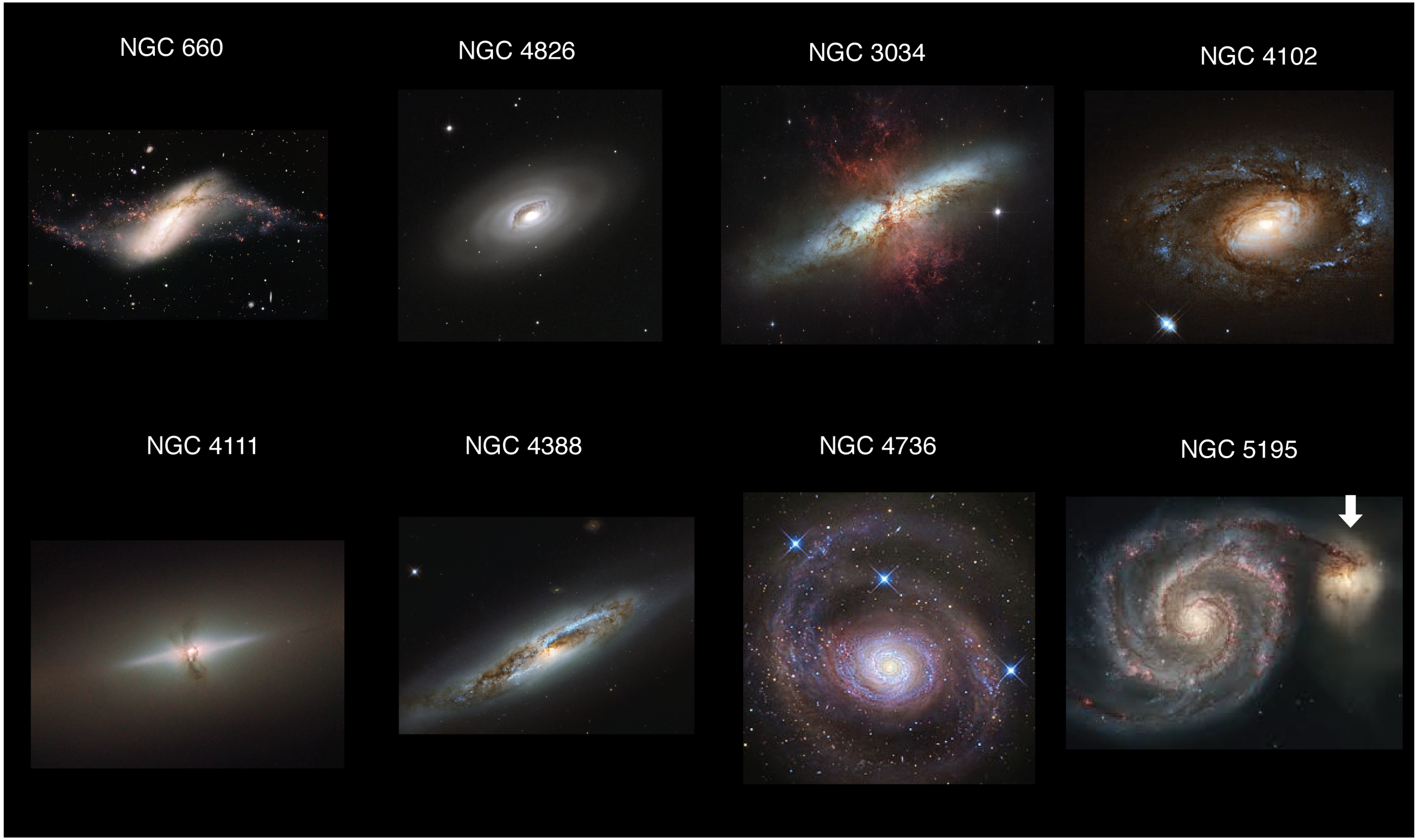


D'Souza et al. 2018b

M31 merged with a progenitor of M32 (M32p) ~2 Gyr ago.
I.e., a galaxy half the size of the MW. Log (M*) ~ 10.3

M32p analogues in the local Universe

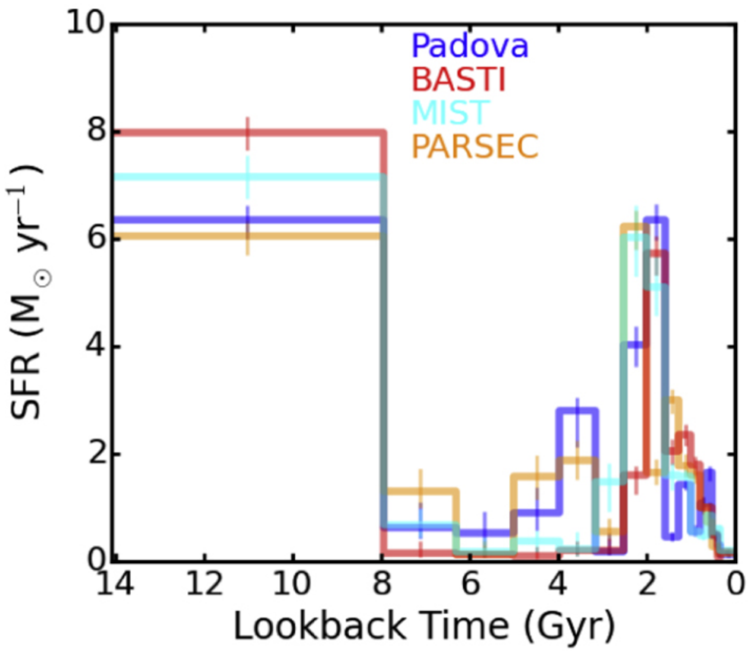
S4G survey out to 24 Mpc



D’Souza et al. 2018b

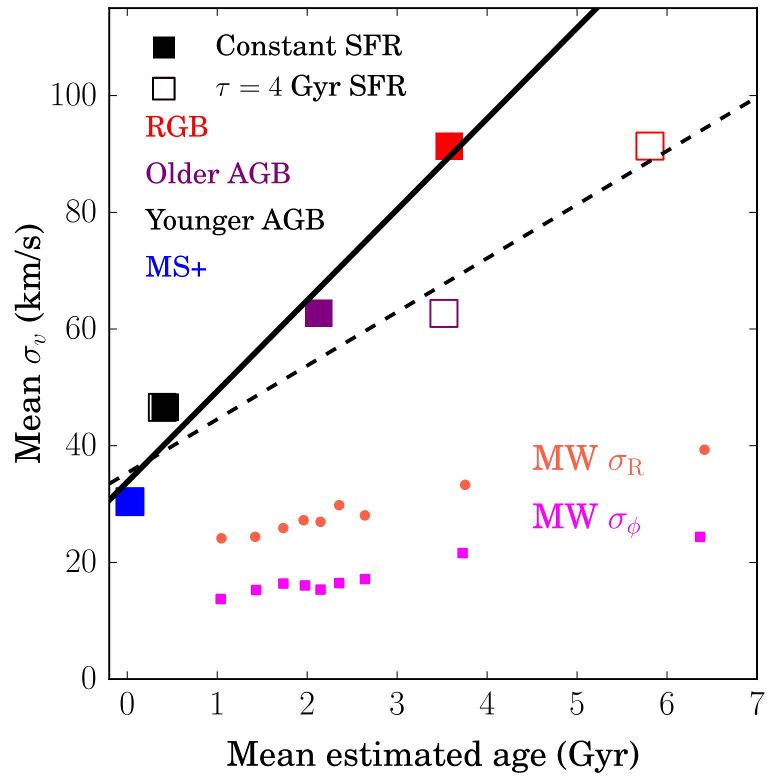
Consequences of the merger in M31

Global burst of Star formation in M31:
~2 Gyr ago



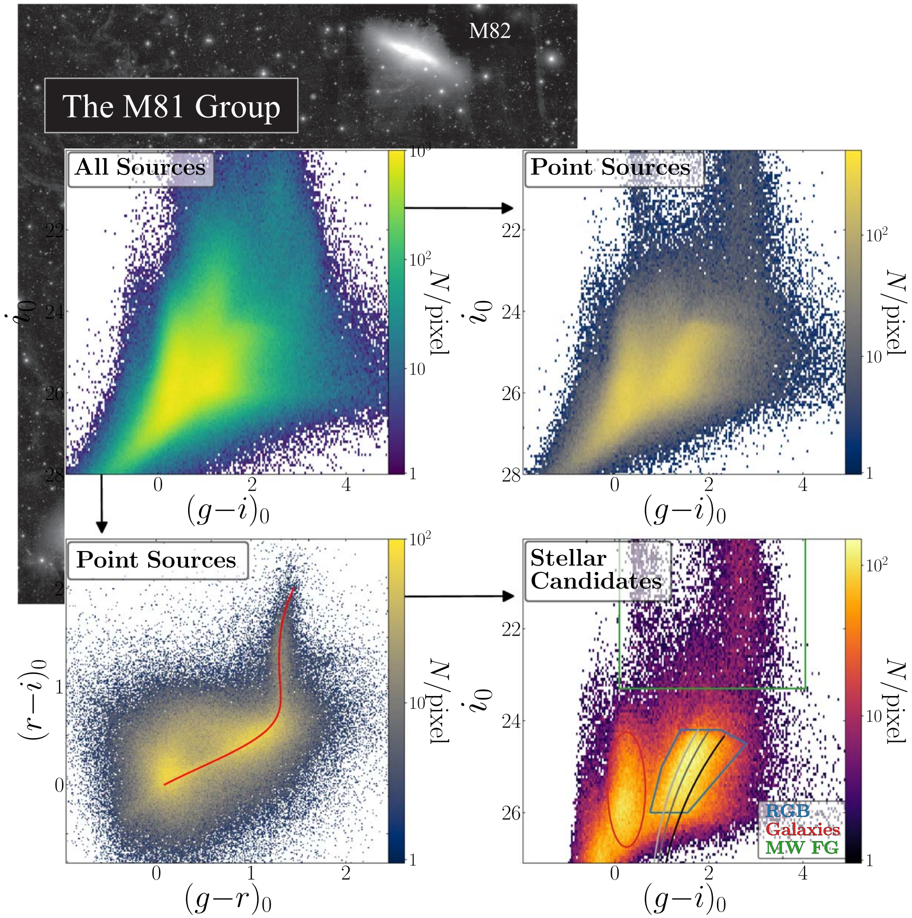
PHAT: Williams et al. 2017

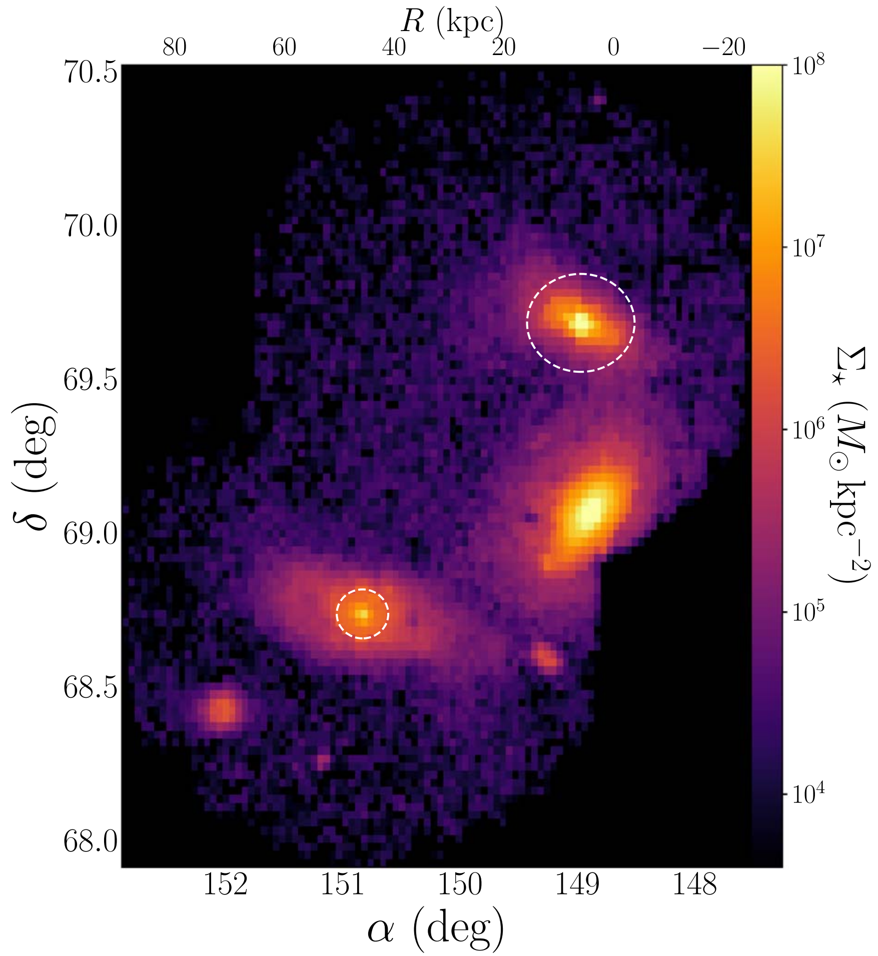
Thickening of M31 disk
Age-velocity dispersion relationship



Dorman et al. 2015

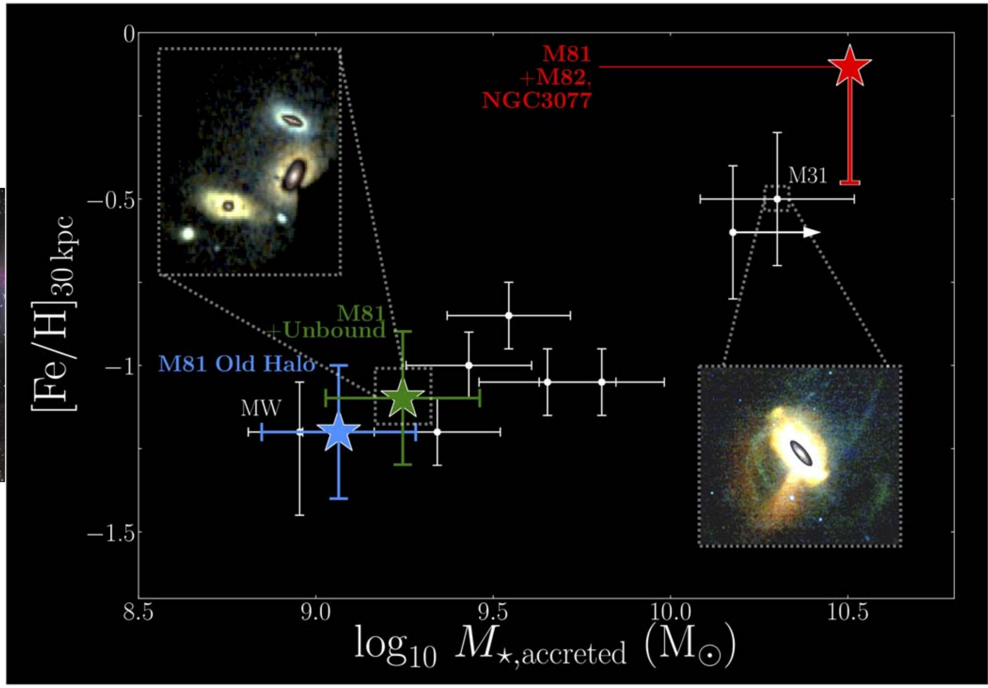
Wide-field imaging of M81's halo





Smercina et al. 2020

M81's future halo



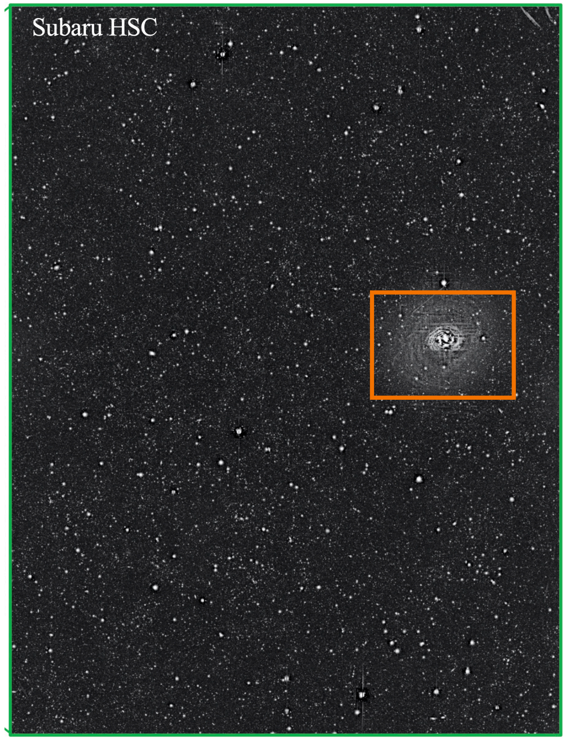
Smercina et al. 2020

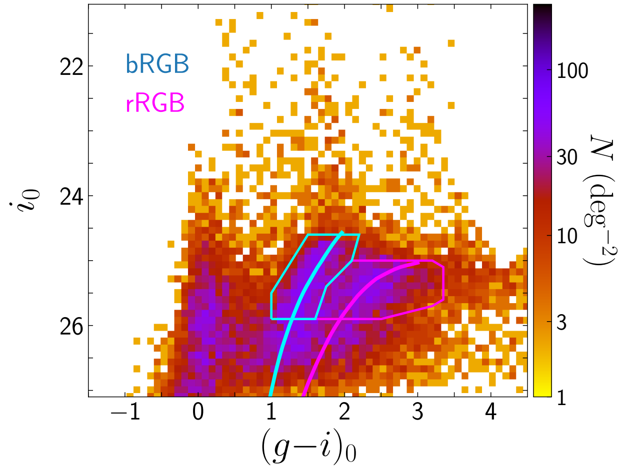
M81 + M82 **M51a + M51b** **M31+M32**

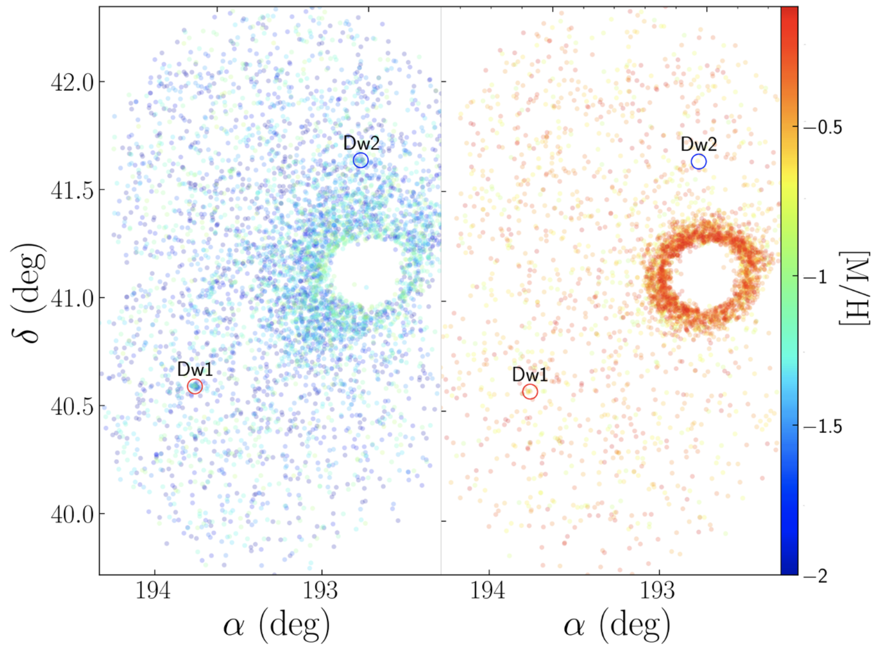
Visually through examples of identified M32p analogues

M94’s stellar halo

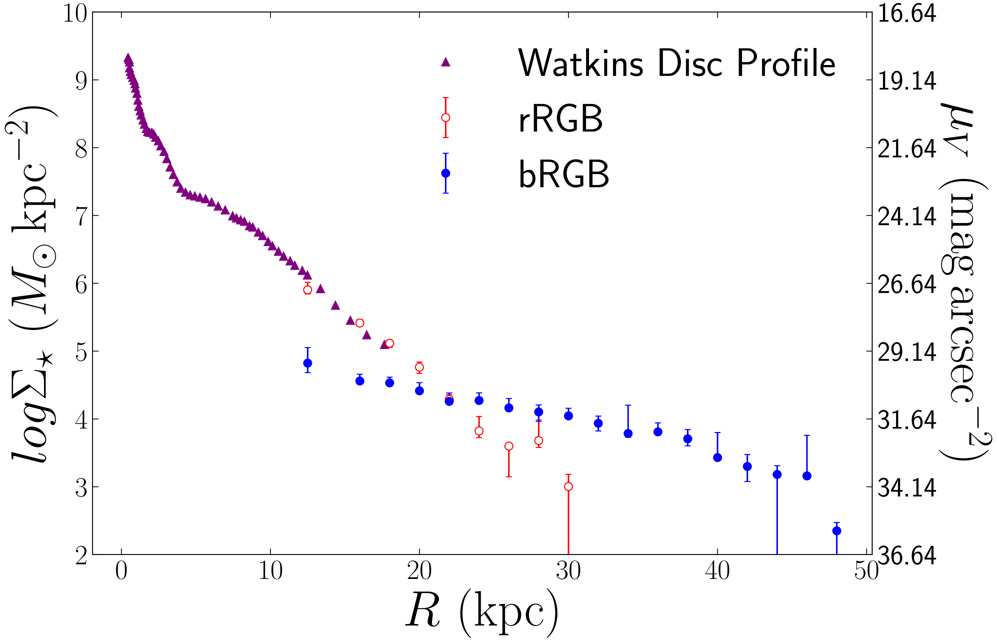
The largest pseudo-bulge host in the Local universe







Gozman et al. 2023 (Under revision)



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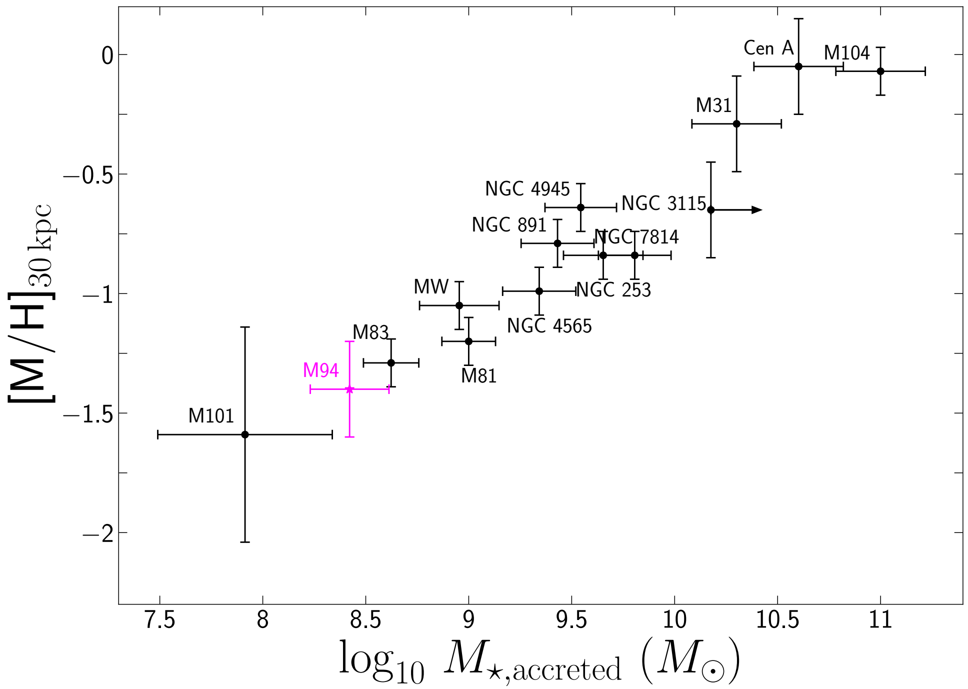
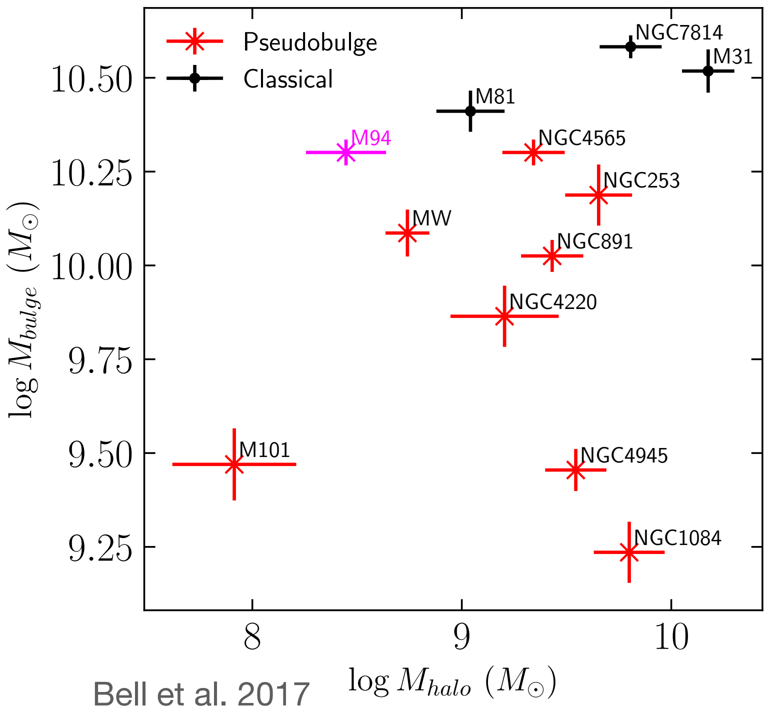
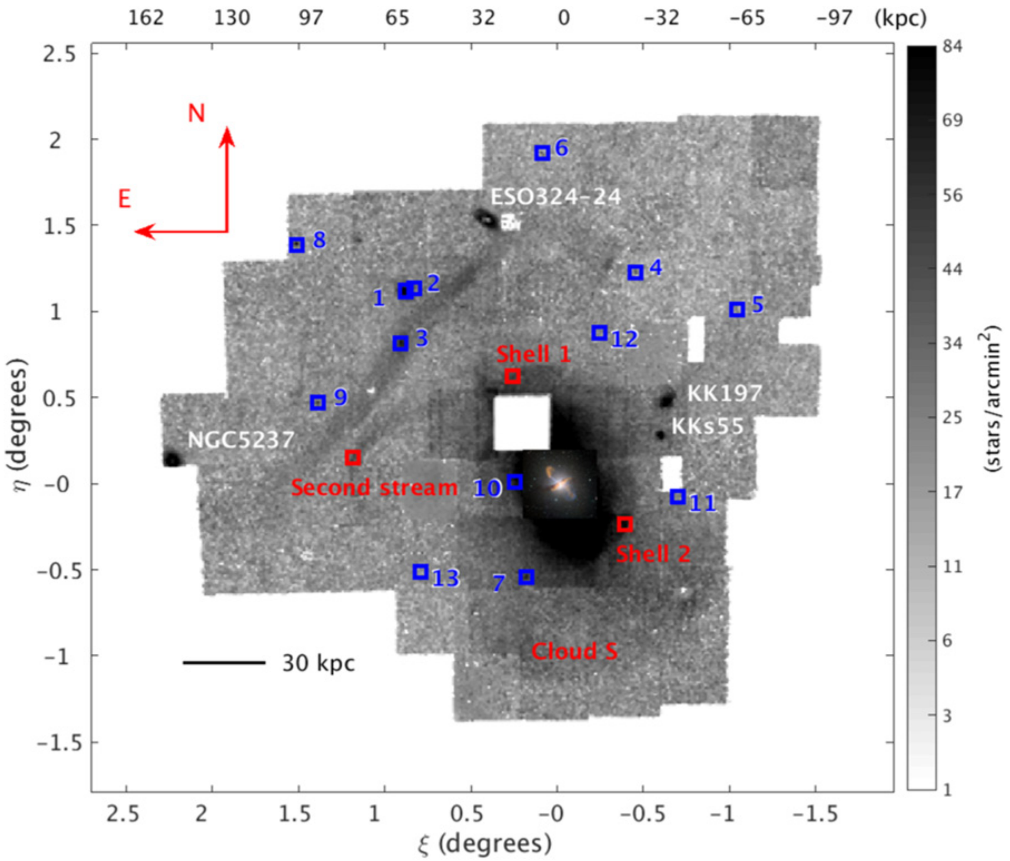




Bell et al. 2017

Infall of satellites with recent large mergers-I

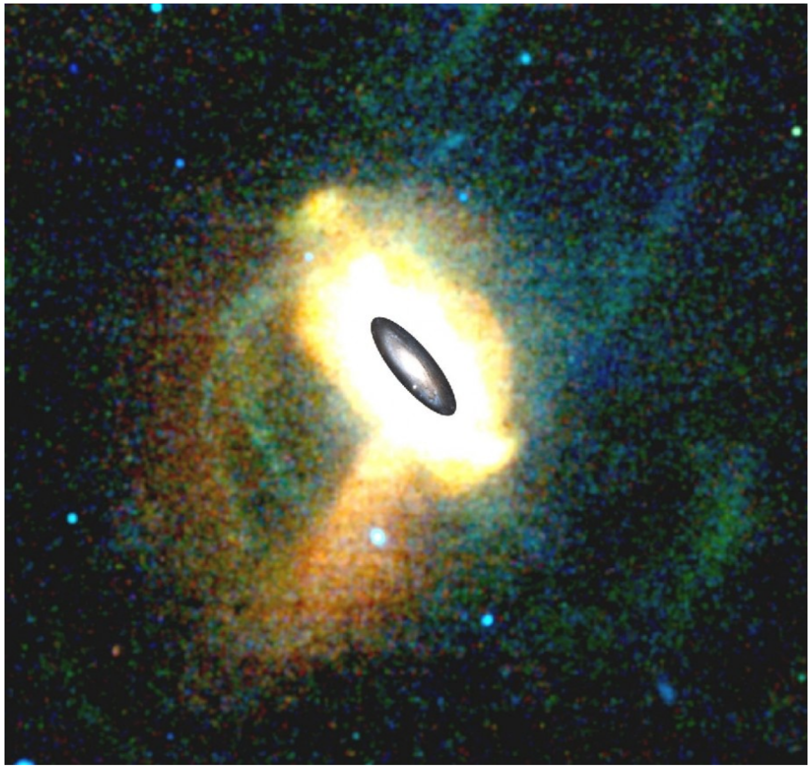
NGC 5128 (Cen A)



PISCES Survey: Crnojevic et al. 2016

Rejkuba et al: 2022 - suffered a collision about ~2-3 Gyr ago

M31 (Andromeda Galaxy)

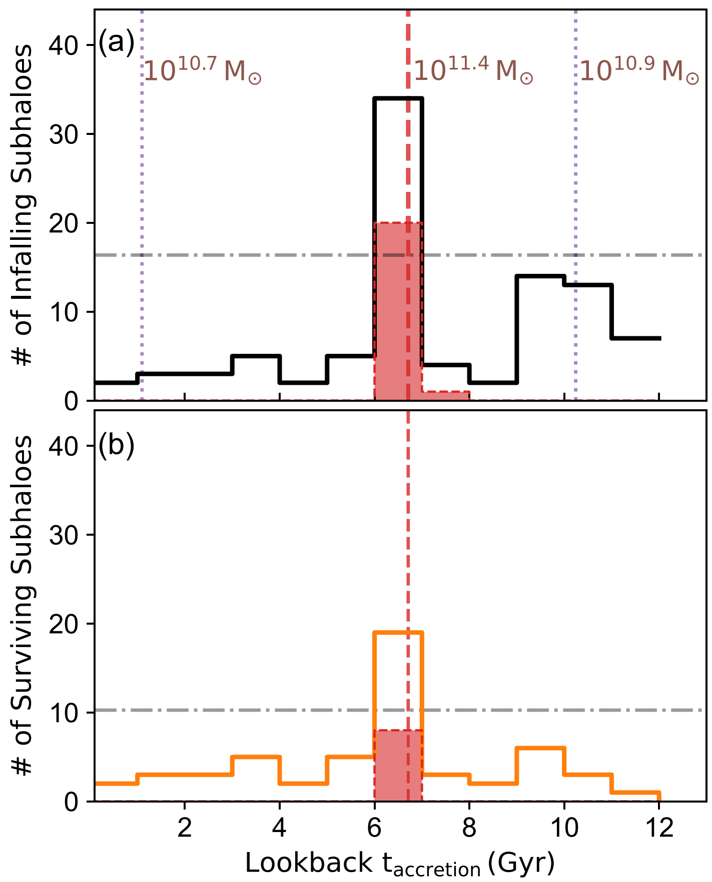


PAndAS Survey: Martins et al. 2013

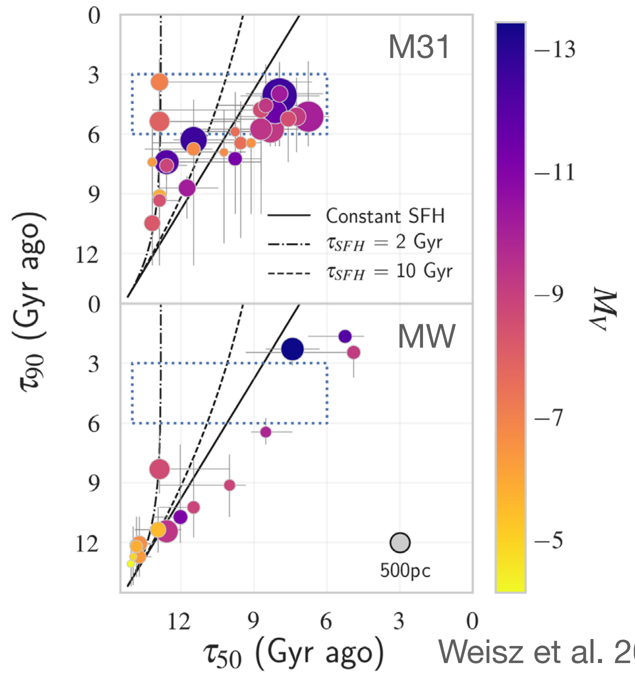
Hammer et al. 2018,D'Souza et al: 2018- suffered a collision about ~2-3 Gyr ago

Large mergers bring in most of the satellite galaxies

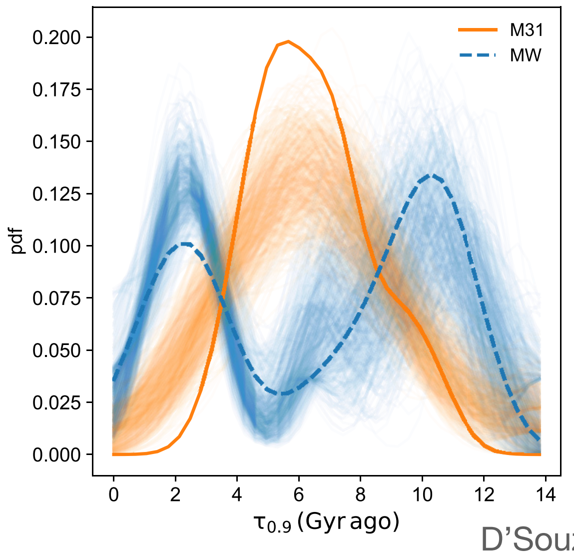
Accretion of simulated M32p galaxy ~7 Gyrs ago



D'Souza et al. 2021

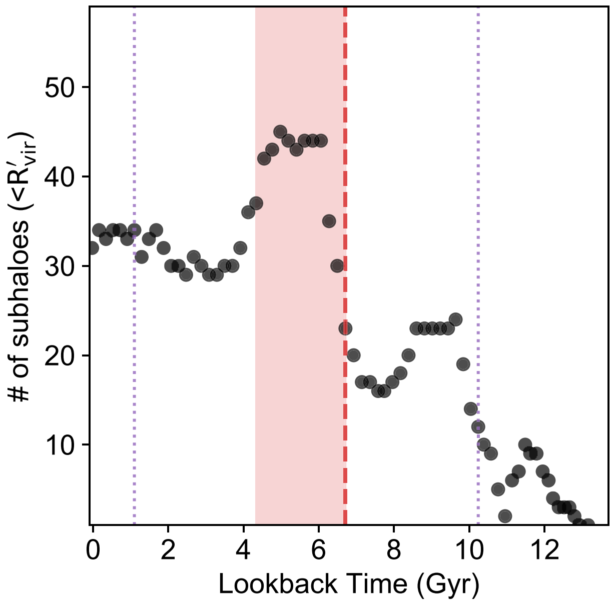


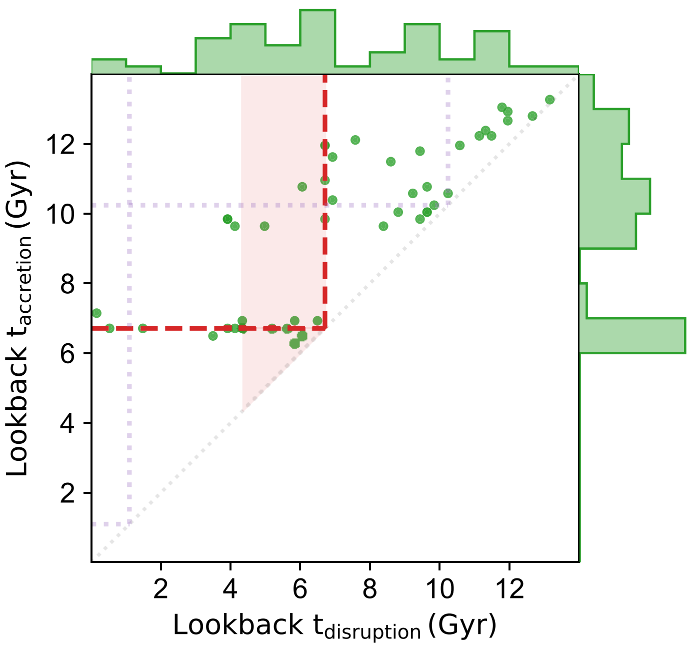
Weisz et al. 2019



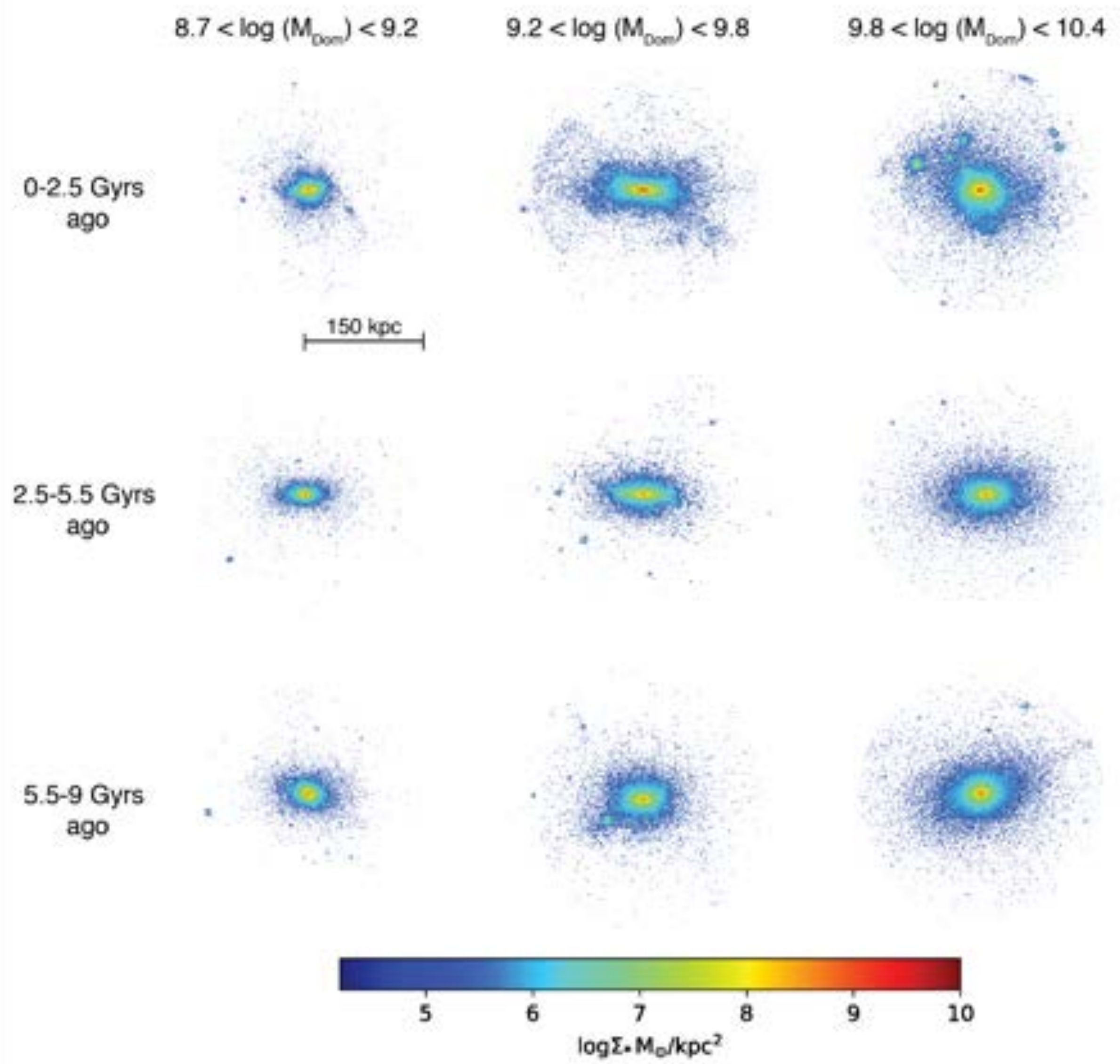
D'Souza et al. 2021

Large mergers precipitate the destruction of dwarf galaxies





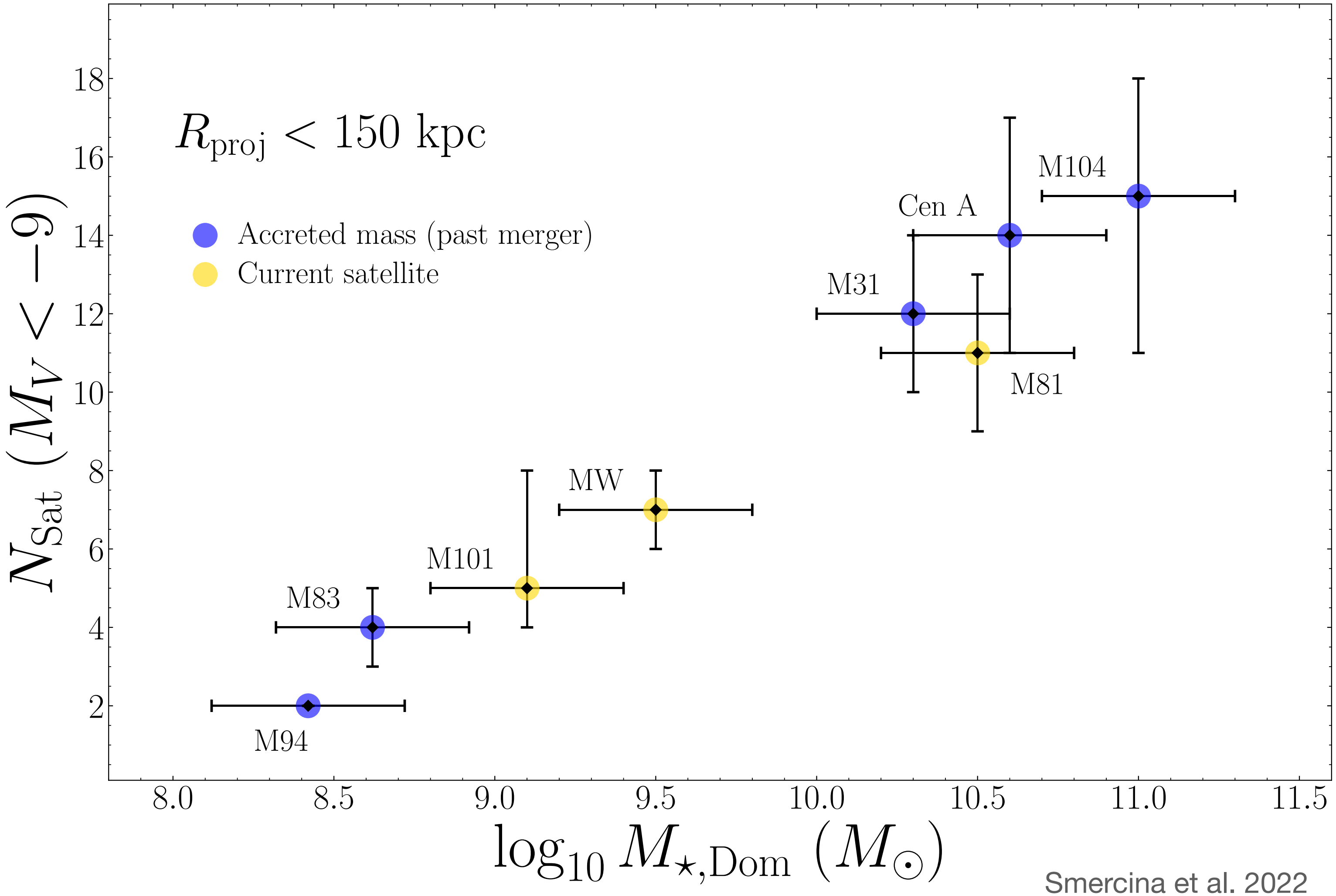
D'Souza et al. 2021



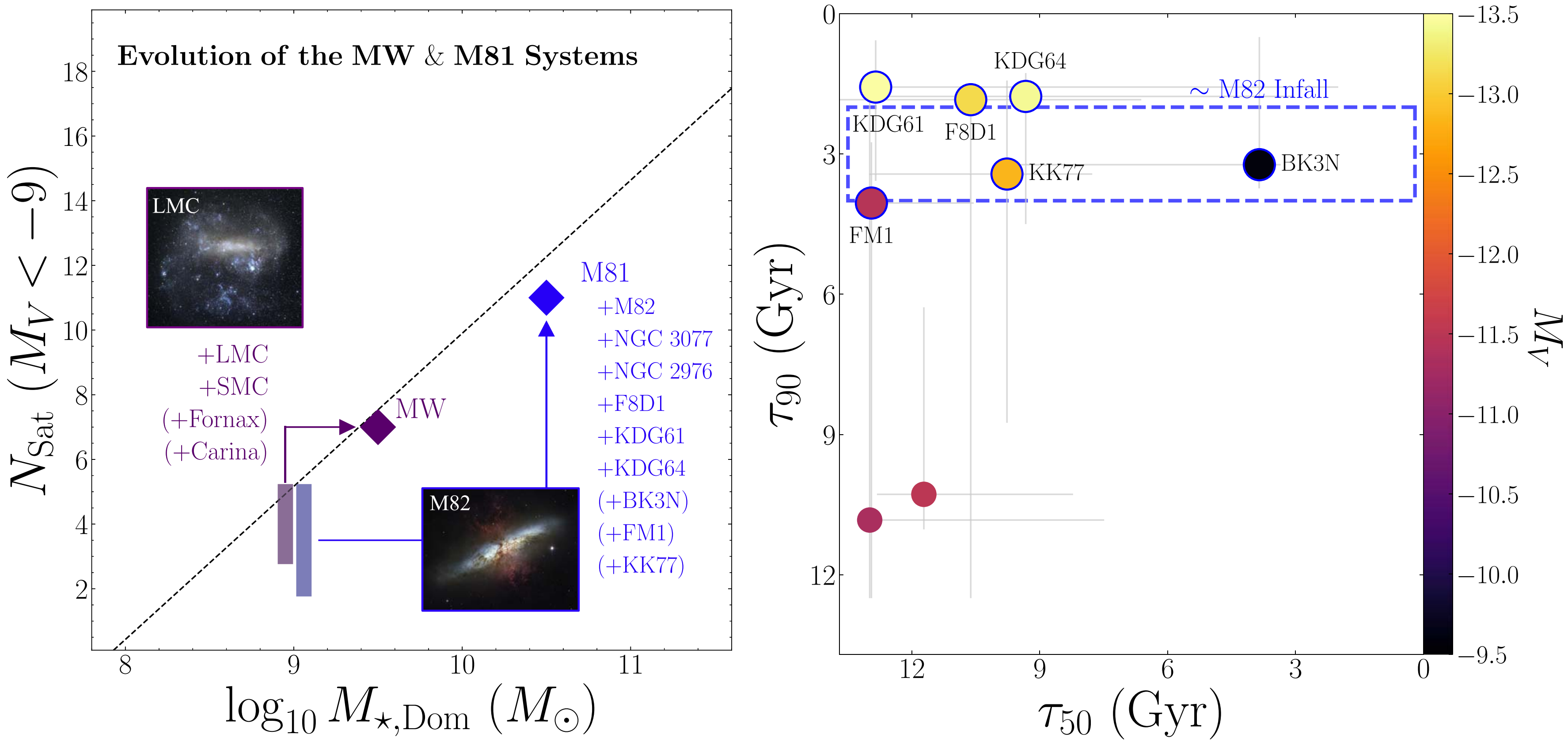
Using the Eagle Simulations

Presence of a large stellar halo and several Sagittarius-like streams is a proxy of a recent large merger.

Mergers bring in satellites

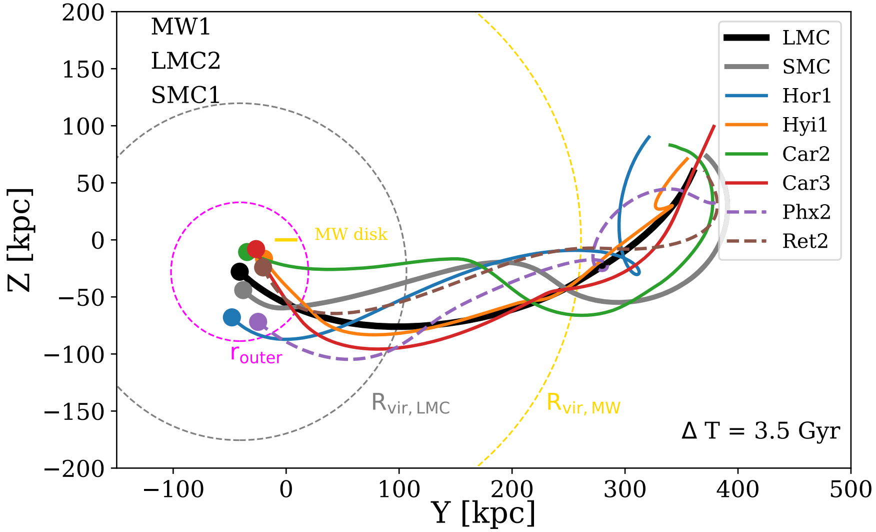


Smercina et al. 2022

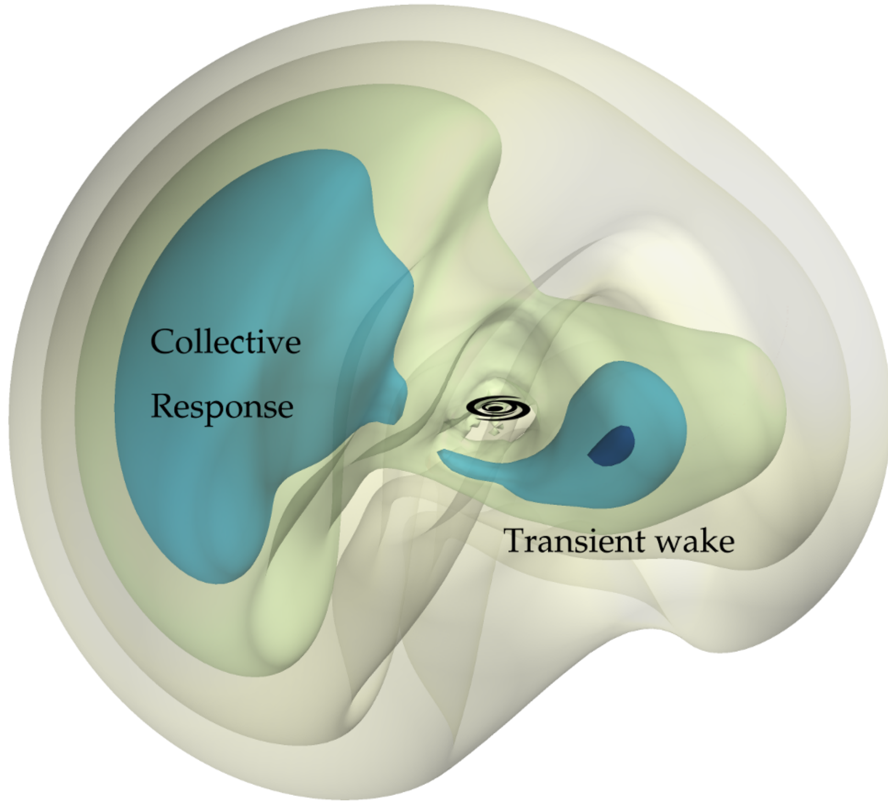


Smercina et al. 2022

The infall times of satellites

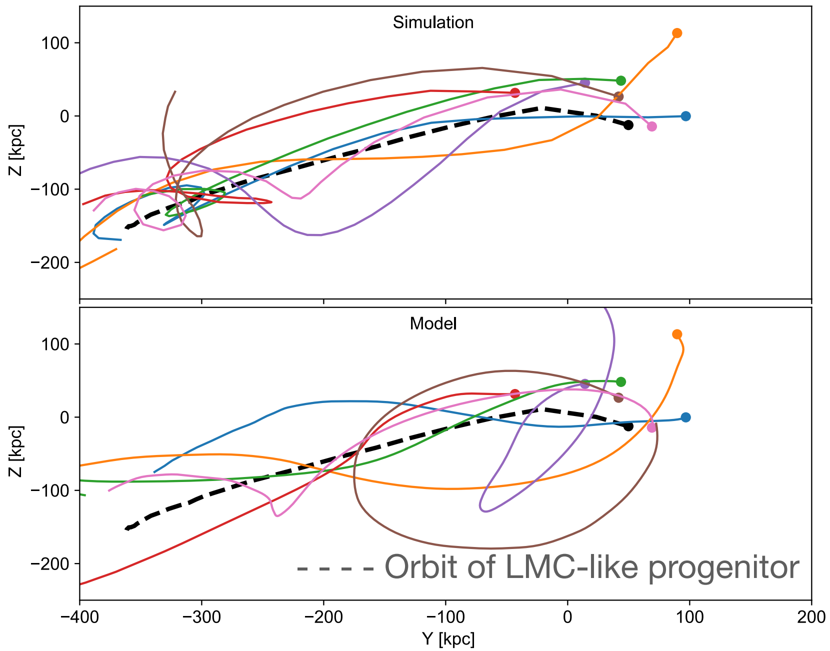


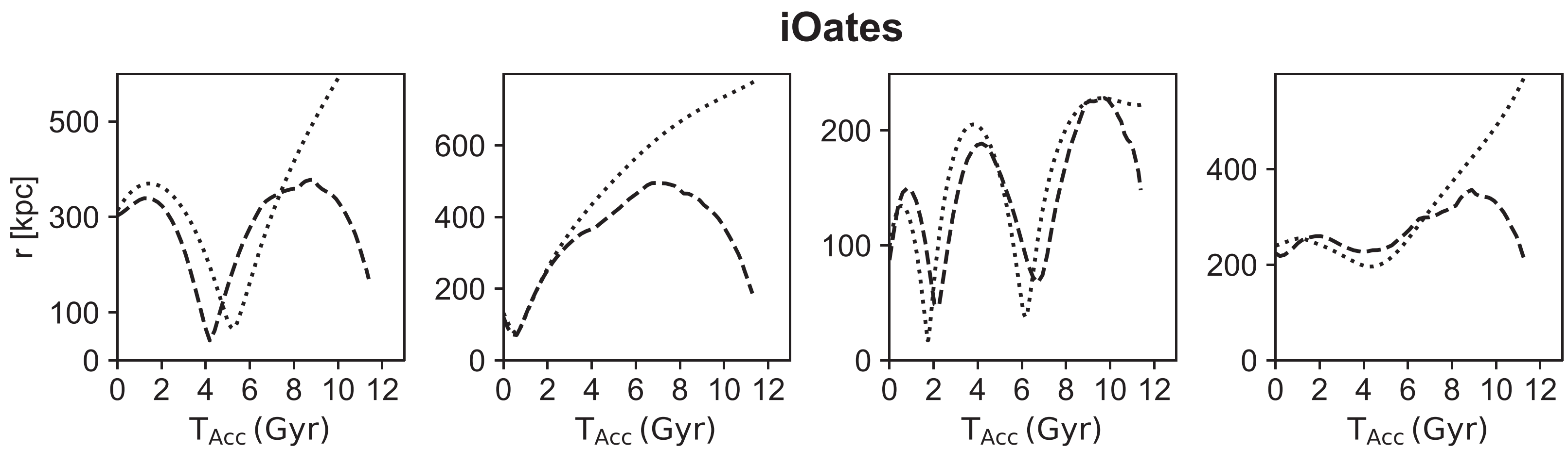
Patel et al. 2020



Garavito Camargo et al. 2021

Difficult to reproduce the exact potential of the MW and LMC

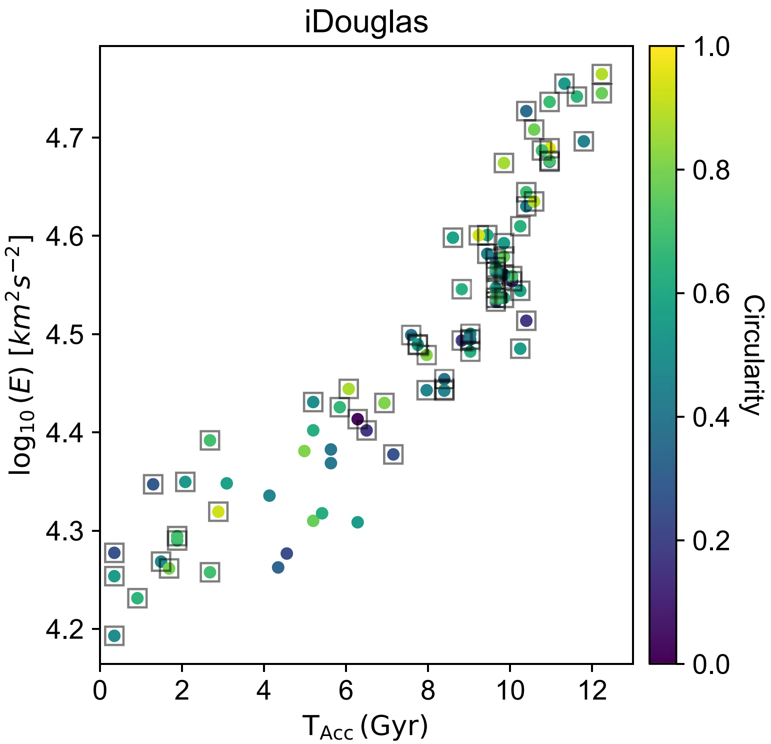




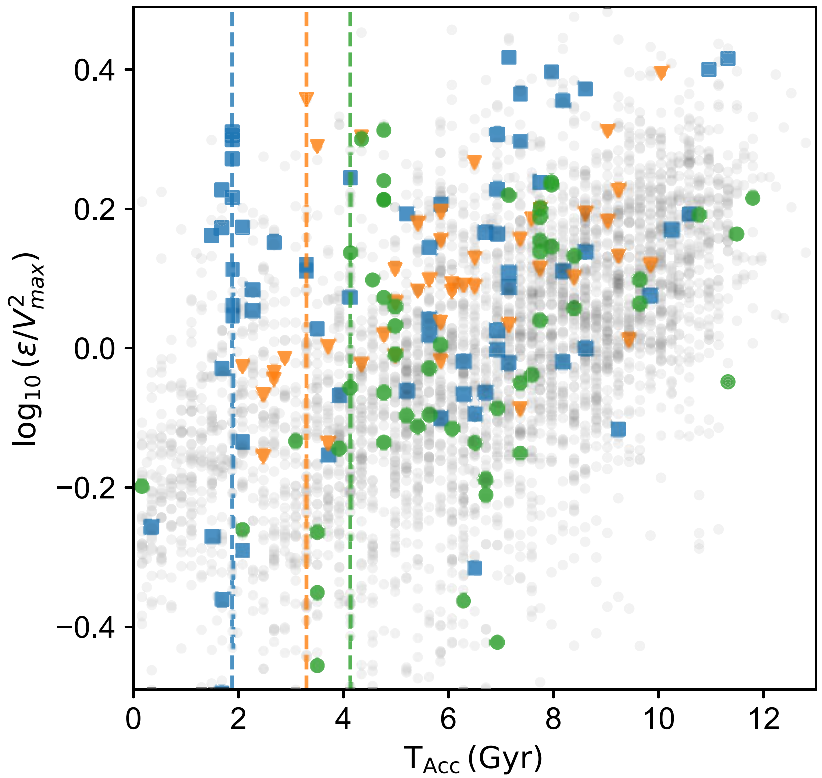
The errors in retracing the exact orbits of the dwarf galaxies due to the rapid changes in potential due to the infall of the LMC.

D'Souza et al. 2022

Clusterings of satellites in Energy and action space?

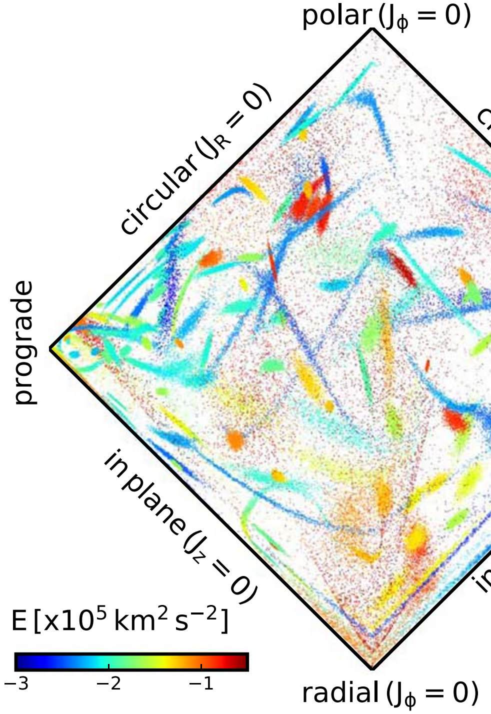


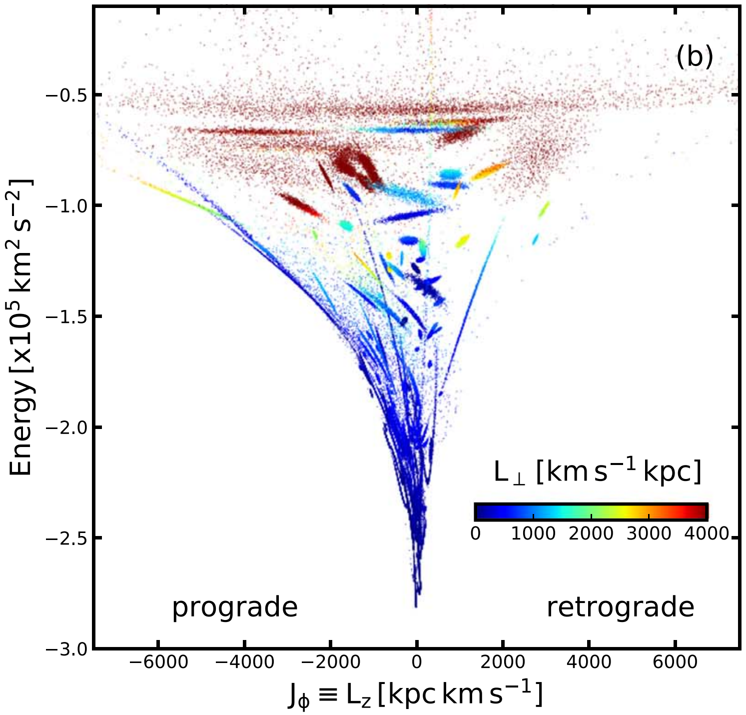
Rocha, Peter & Bullock (2012)



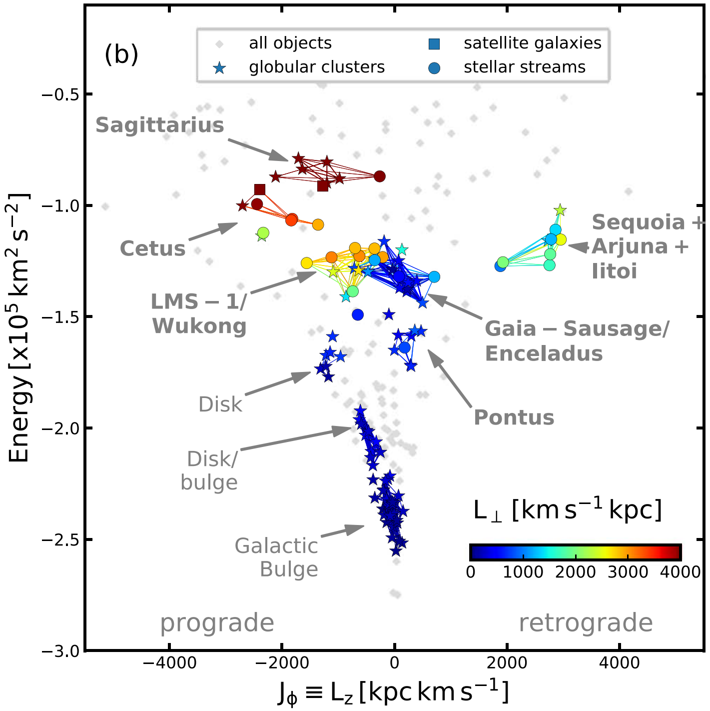
D'Souza et al. 2022

n=170 Globular Clusters in (**J**, E) space

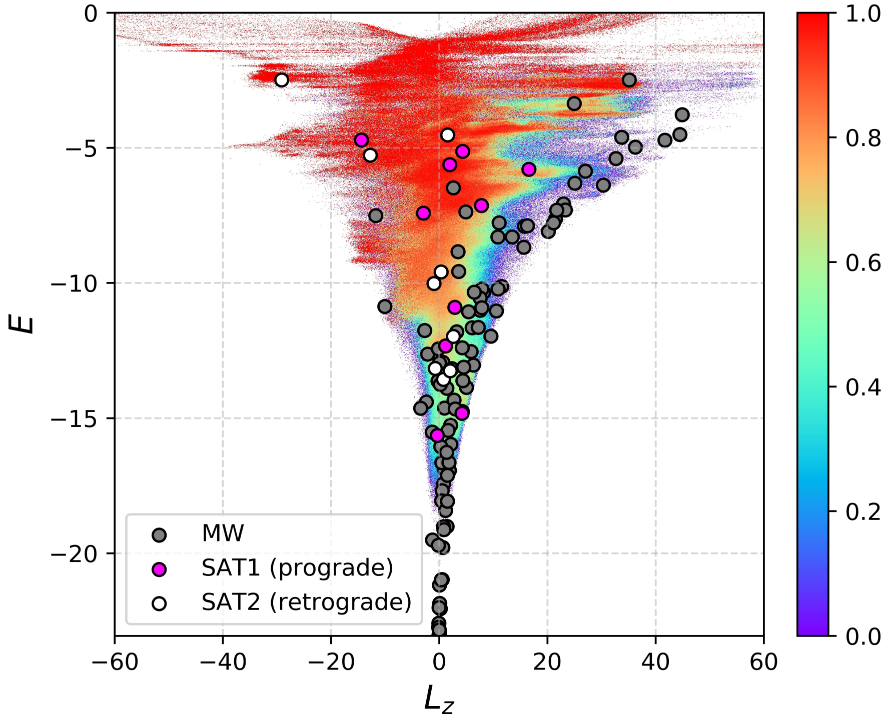




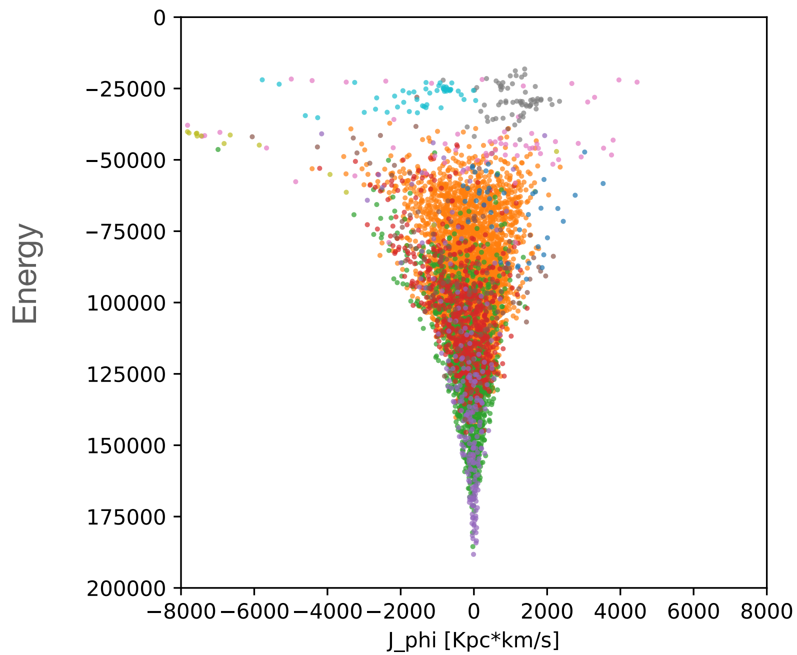
Malhan et al. 2022

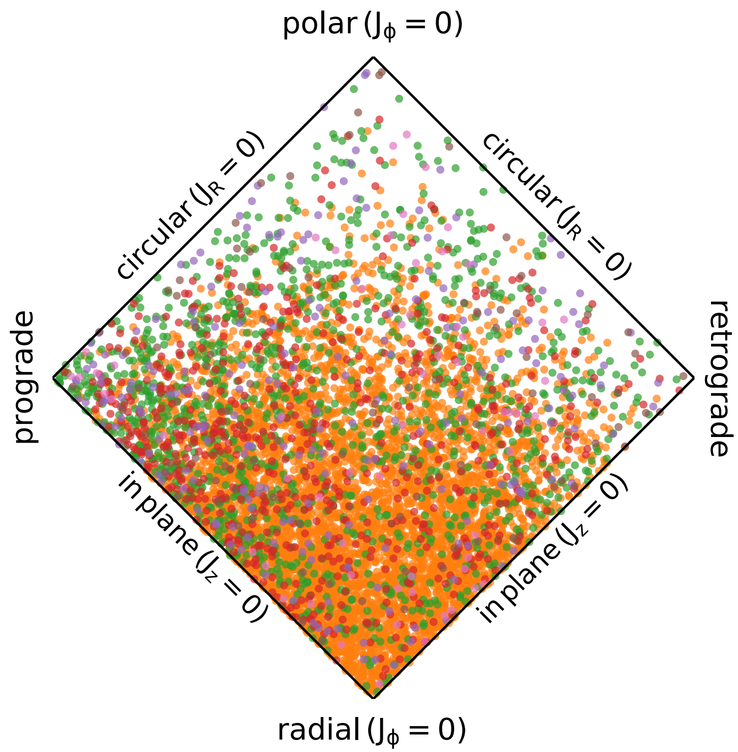


Tests from Milky-Way analogue in TNG50



Pagnini et al 2022





Scattering of binding energy and actions of the progenitor.
Overlap in action-BE space with various progenitors.

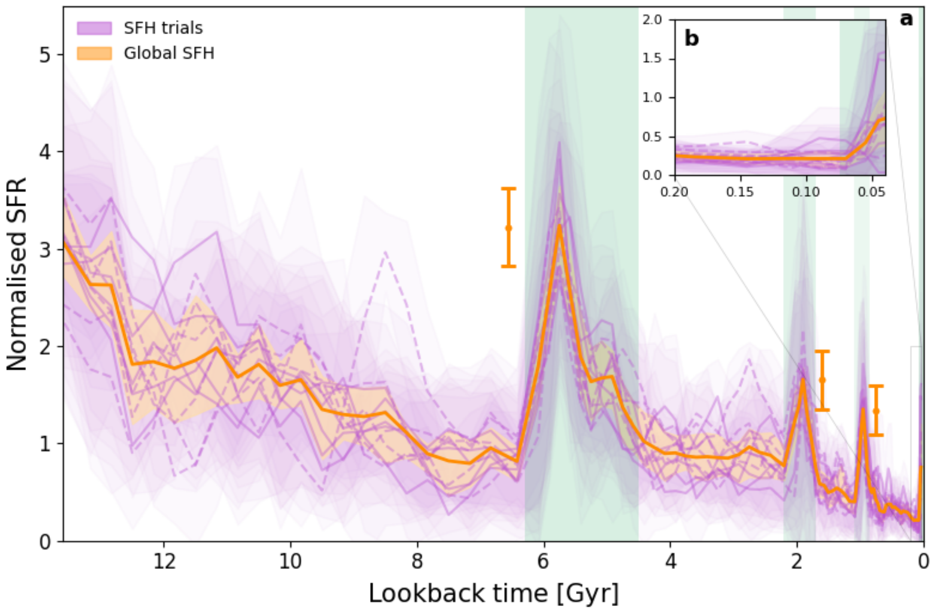
Conclusions

- We have identified the last major merger of the MW, and the effects of that merger on the galaxy thanks to Gaia and spectroscopic surveys.
- We are slowly extending this knowledge to other MW-mass galaxies in the Local Volume.We have identified the most dominant mergers (mass and infall time) of M31, Cen A, M81, M64, M101, NGC253, NGC891, and we are beginning to understand the effects of these mergers on these galaxies.
- These large mergers contribute to the heating of a galactic disk, a burst of star formation and the accretion of smaller satellite galaxies, but do not contribute substantially to the building of their central bulges.
- The accretion of a large satellite causes a scattering in binding energies/actions of satellites/globular clusters accreted along with it.
- For back integration of satellites, we need better dynamic models of the potential of the MW and the LMC.

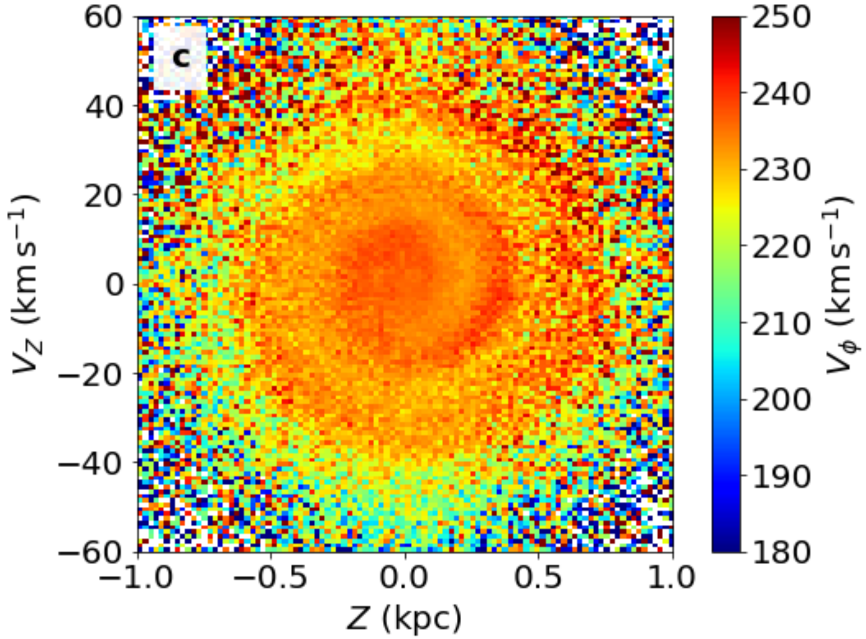
Extra slides

MW-mass galaxies in the Local Volume

Impact of Sagittarius



Ruiz-Lara et al. 2020



Antoja et al. 2018