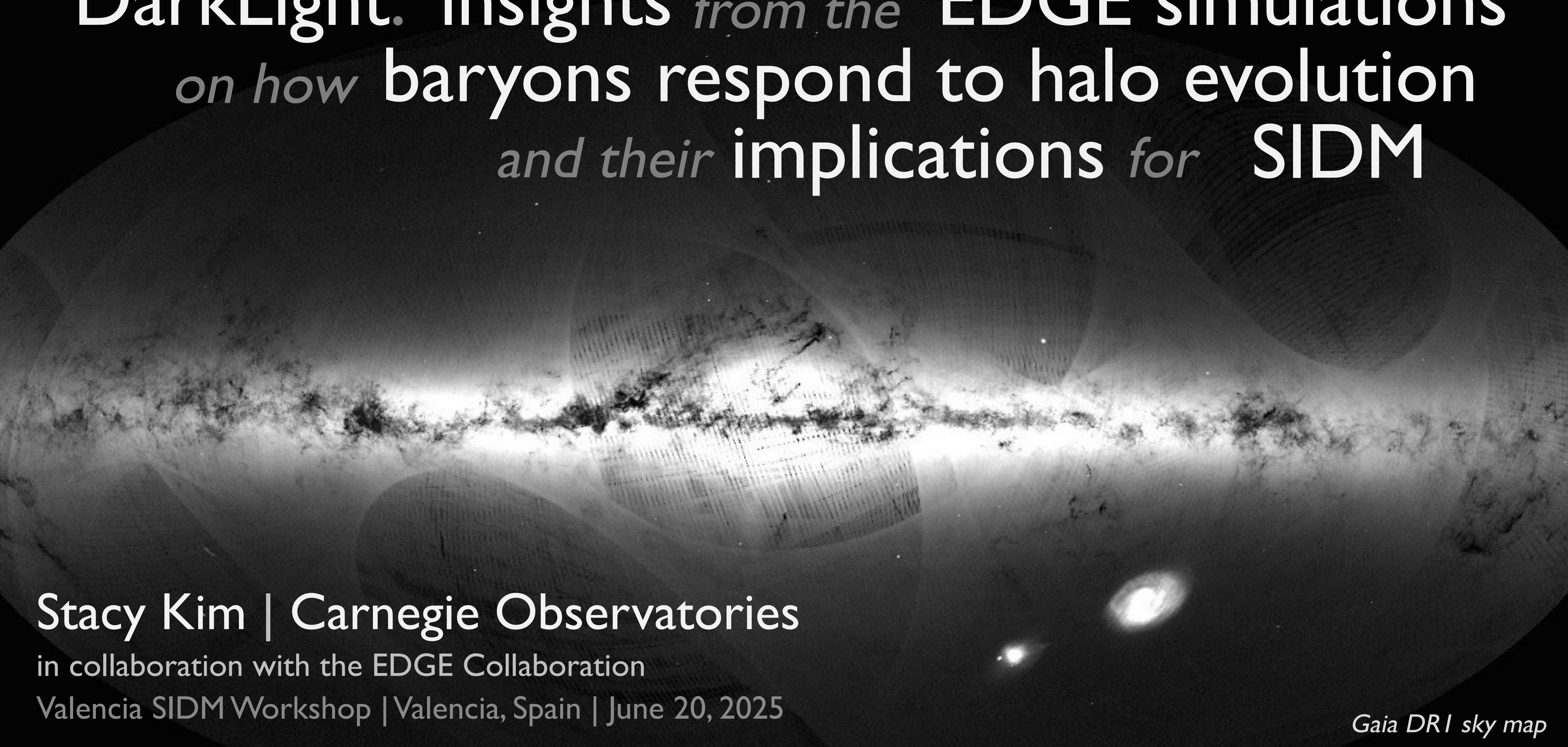
DarkLight: insights *from the* EDGE simulations *on how* baryons respond to halo evolution *and their* implications *for* SIDM

Stacy Kim | Carnegie Observatories

in collaboration with the EDGE Collaboration

Valencia SIDM Workshop | Valencia, Spain | June 20, 2025



Gaia DR1 sky map

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Gaia DR1 sky map

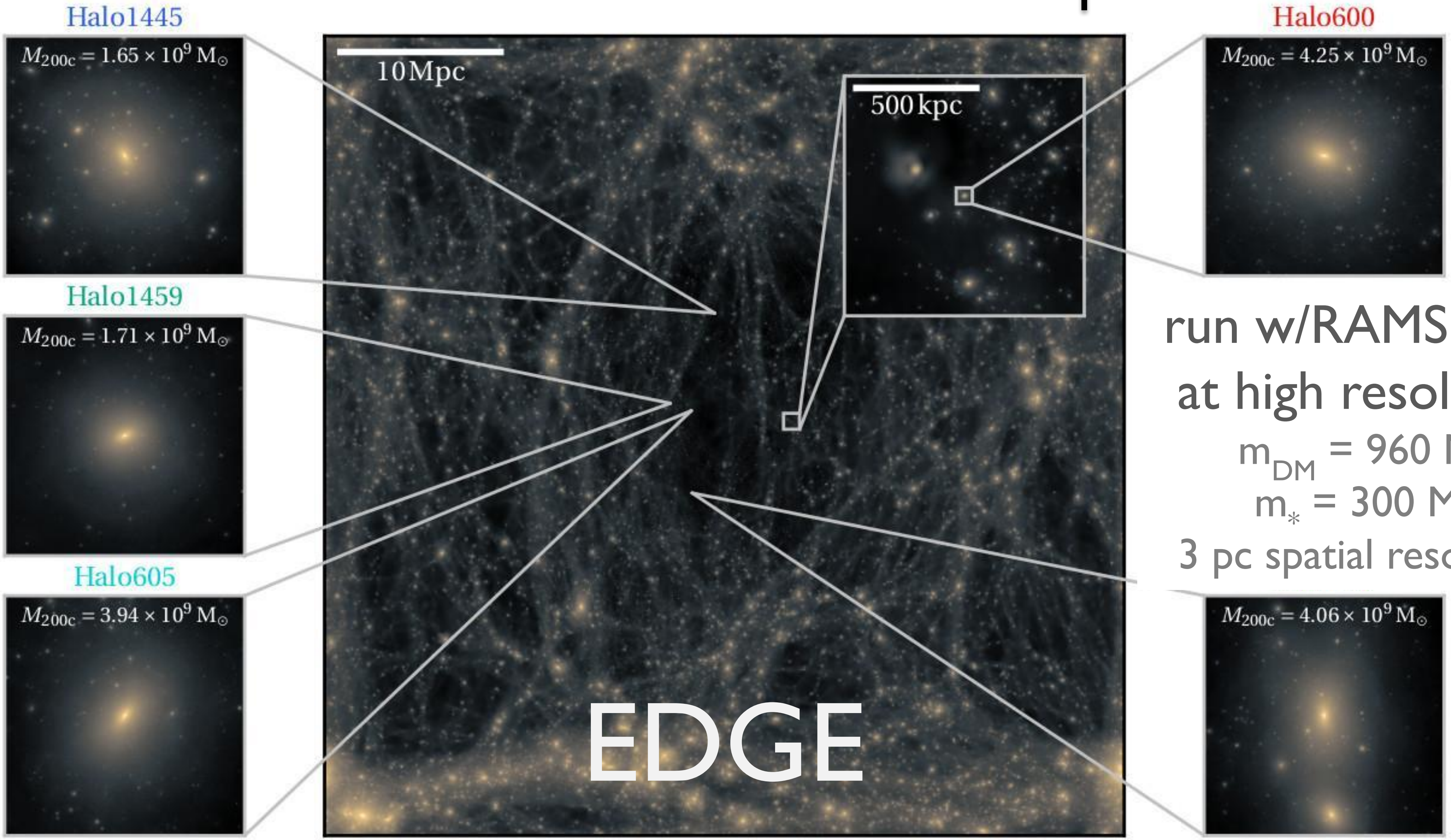
Dark matter only simulations in SIDM
can be expensive, especially with core collapse.

Baryonic simulations in SIDM
are even more expensive.

We need a faster way to reliably compute observable properties of many galaxies in SIDM!

(see talks by Moritz Fischer, Andrew Wetzel)

how halo evolution affects baryons | EDGE



run w/RAMSES-RT at high resolution

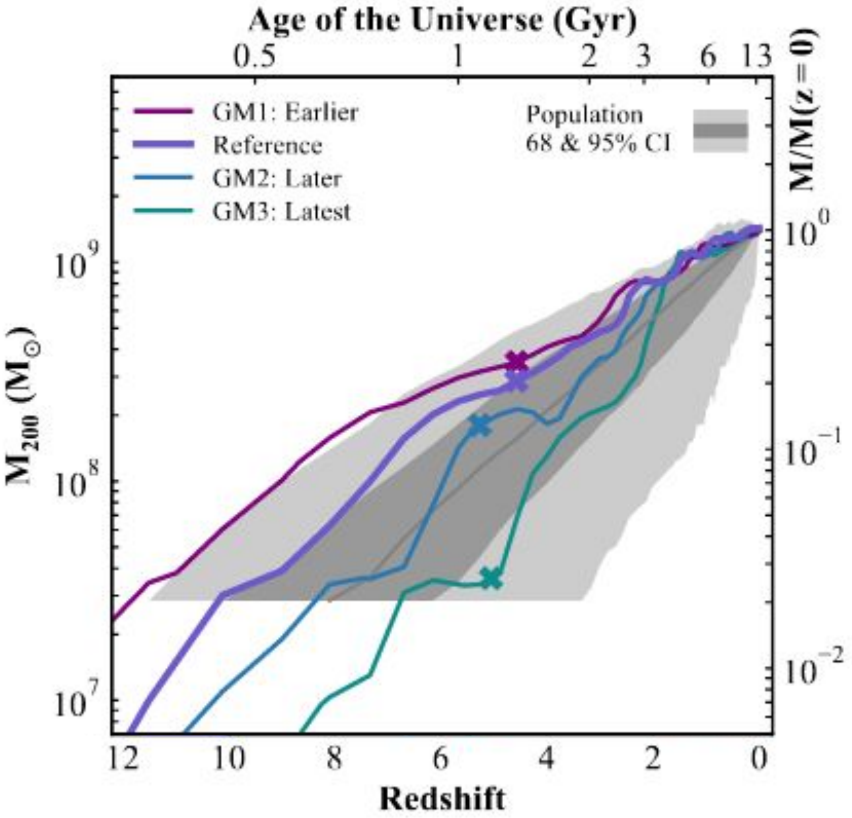
$m_{DM} = 960\ M_\odot$

$m_* = 300\ M_\odot$

3 pc spatial resolution

Orkney+ 2021, Agertz+ 2020

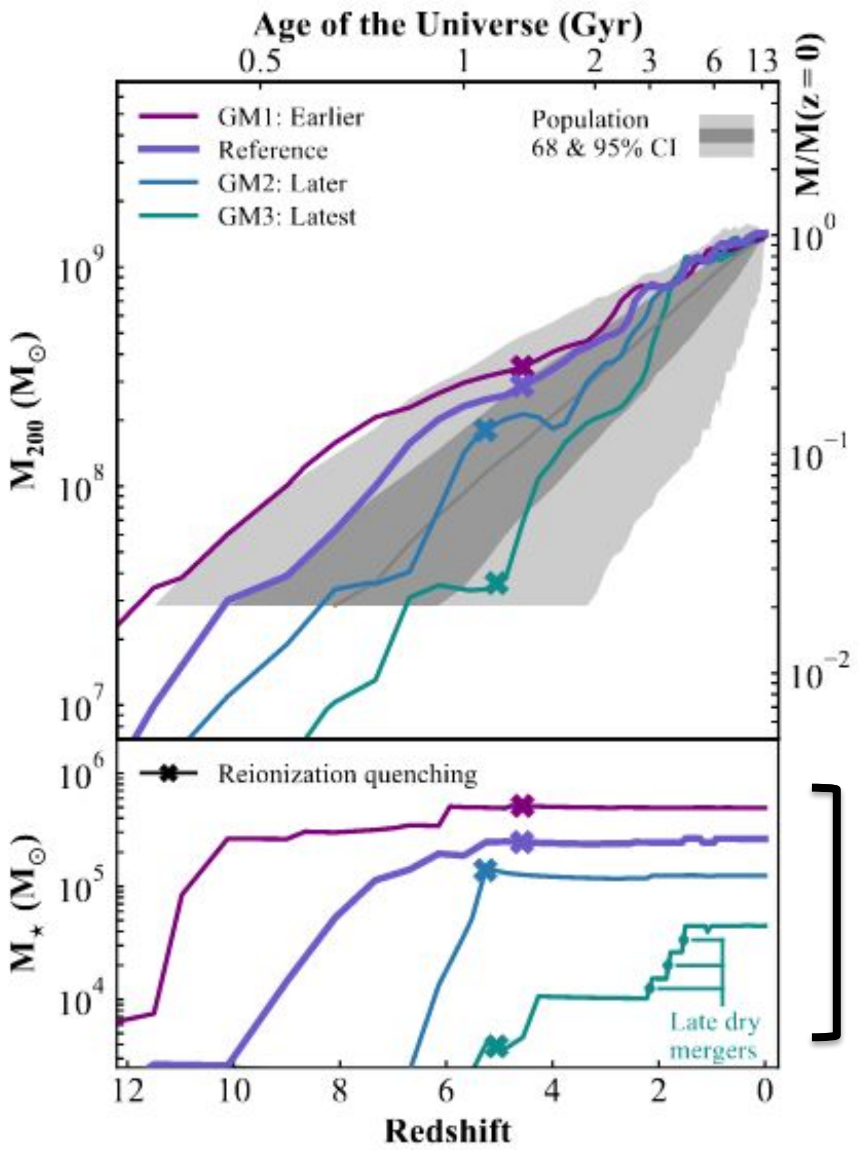
how halo evolution affects baryons | EDGE



"genetically modified" one DM halo to grow at different rates

Rey+ 2019

how halo evolution affects baryons | EDGE



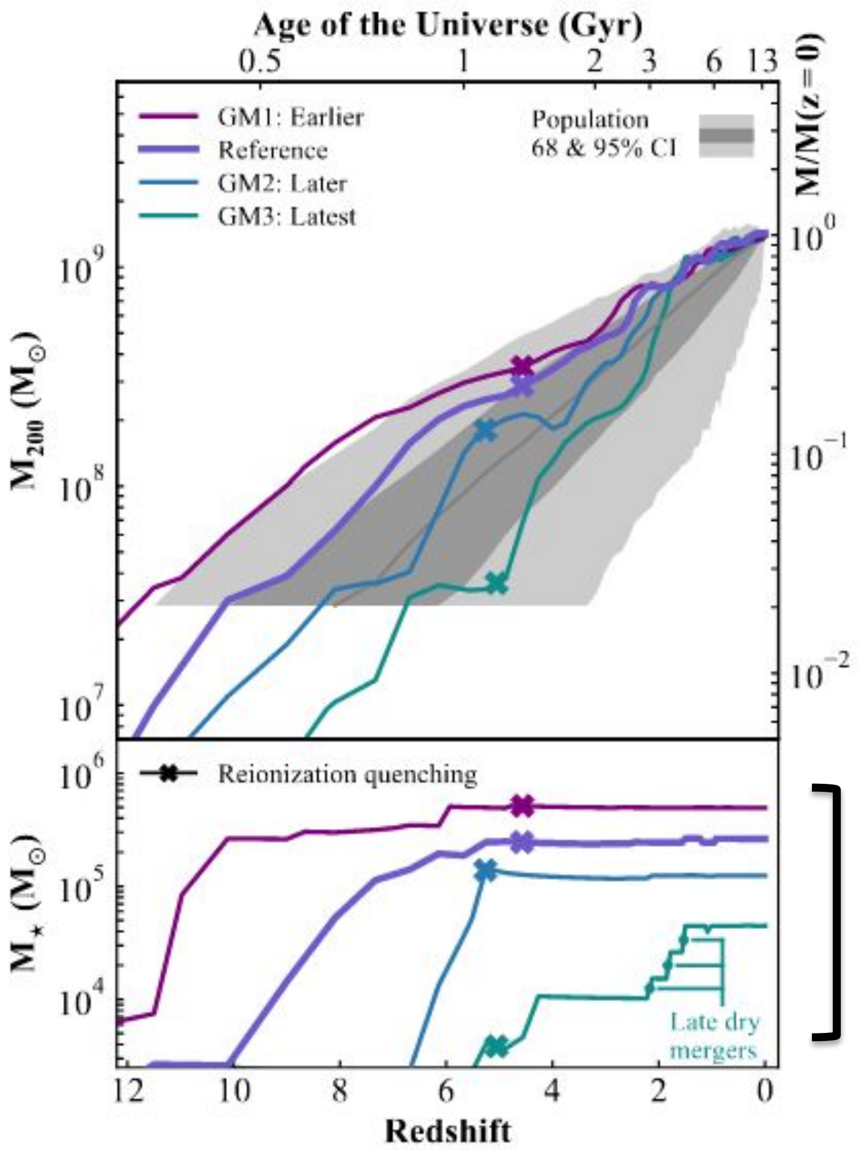
"genetically modified" one DM halo to grow at different rates

resultant dwarf *galaxy* masses sensitive to *dark matter* accretion history

differ by 1 dex!

Rey+ 2019

how halo evolution affects baryons | EDGE



"genetically modified" one DM halo to grow at different rates

Scatter in DM accretion histories may account for majority of scatter in galaxy mass.

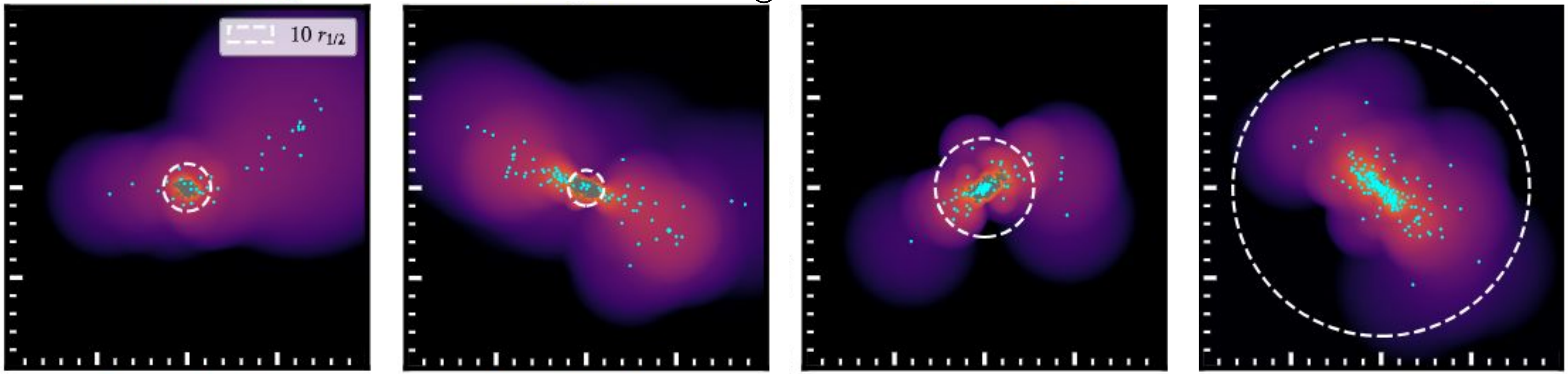
resultant dwarf *galaxy* masses sensitive to *dark matter* accretion history

differ by 1 dex!

Rey+ 2019

how halo evolution affects baryons | EDGE

"Genetically modified" one $10^9\ M_\odot$ DM halo to grow at different rates:



earlier forming ⟵⟶ later forming

Rey+ 2019, Goater+, incl SYK 2023

how halo evolution affects baryons | EDGE

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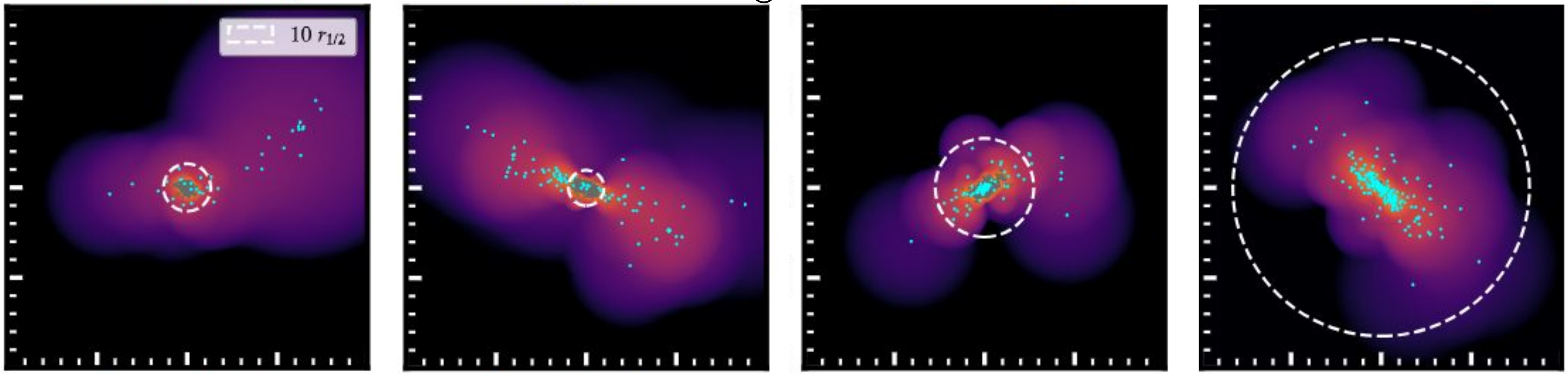

earlier forming ⟷ later forming

higher stellar mass | lower stellar mass

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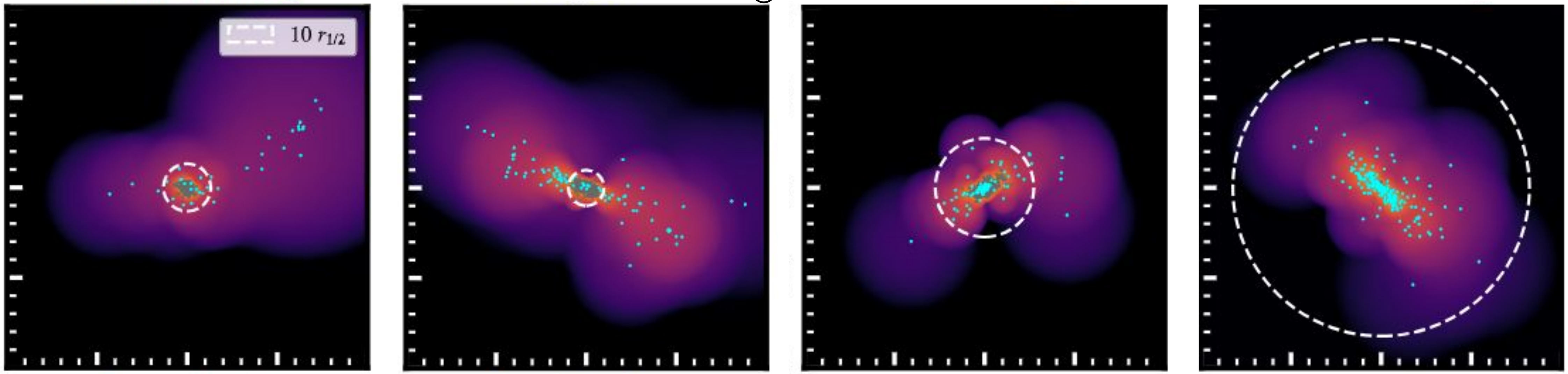

earlier forming ⟷ later forming

higher stellar mass
stars mainly formed in-situ

lower stellar mass
stars mainly accreted

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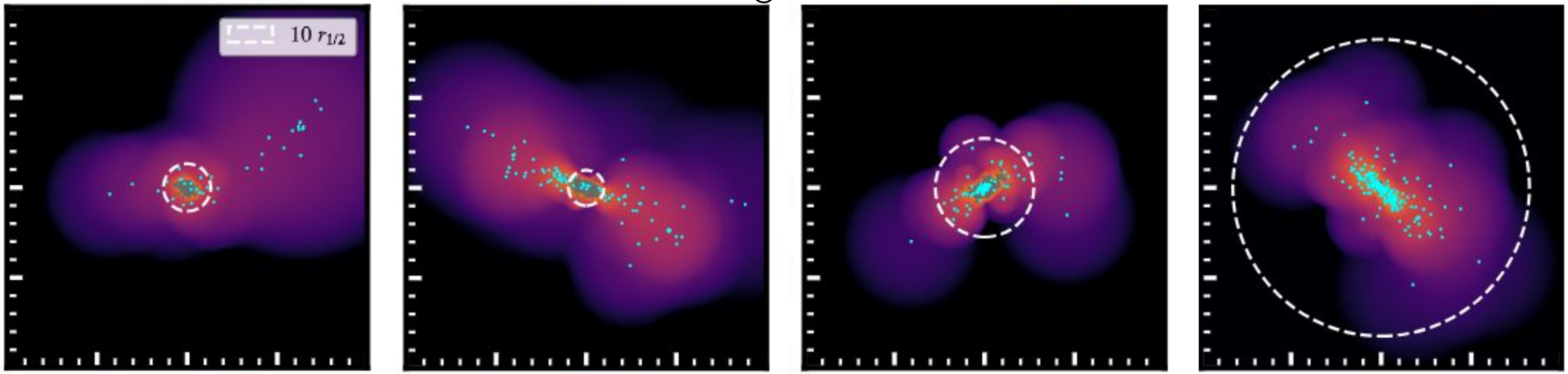

earlier forming ⟷ later forming

higher stellar mass
stars mainly formed in-situ
smaller galaxy size

lower stellar mass
stars mainly accreted
larger galaxy size (circles = 10 half-light radii)

Rey+ 2019, Goater+, incl SYK 2023

how halo evolution affects baryons | EDGE

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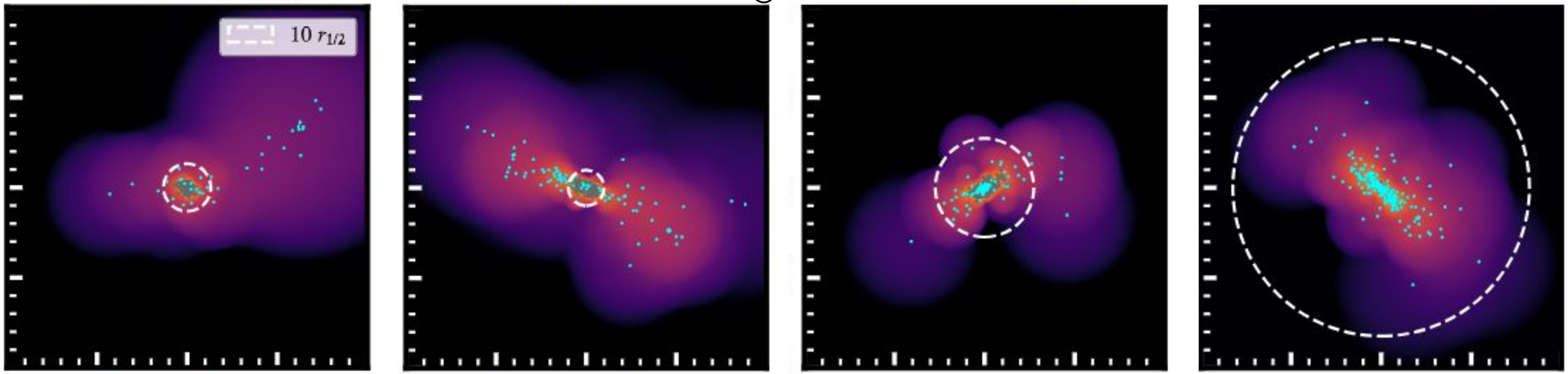

earlier forming ⟷ later forming

higher stellar mass
stars mainly formed in-situ
smaller galaxy size
more circular

lower stellar mass
stars mainly accreted
larger galaxy size (circles = 10 half-light radii)
more elliptical

Rey+ 2019, Goater+, incl SYK 2023

how halo evolution affects baryons | EDGE

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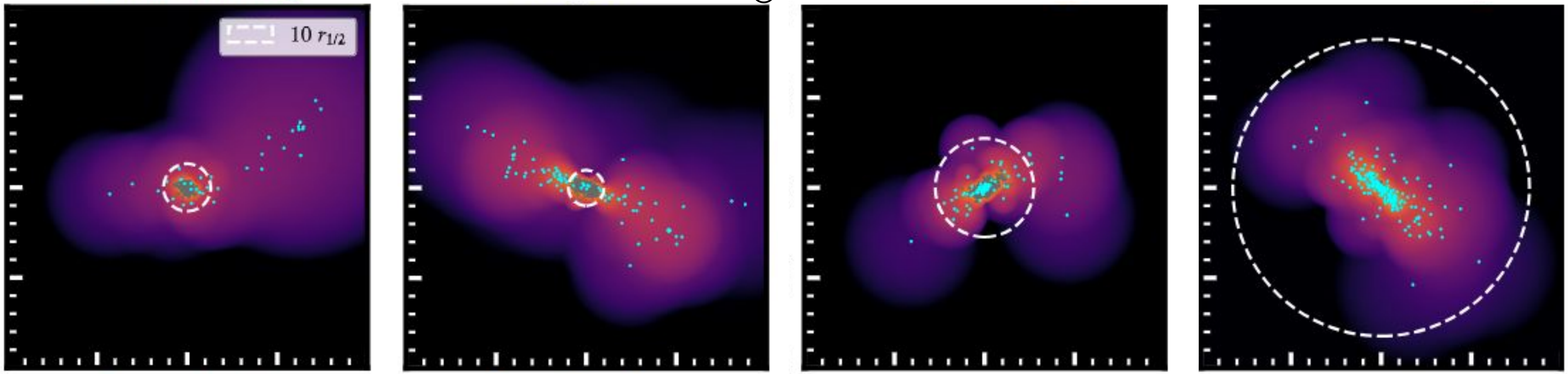

earlier forming ⟷ later forming

higher stellar mass	lower stellar mass
stars mainly formed in-situ	stars mainly accreted
smaller galaxy size	larger galaxy size (circles = 10 half-light radii)
more circular	more elliptical
higher metallicity	lower metallicity

Rey+ 2019, Goater+, incl SYK 2023

how halo evolution affects baryons | EDGE

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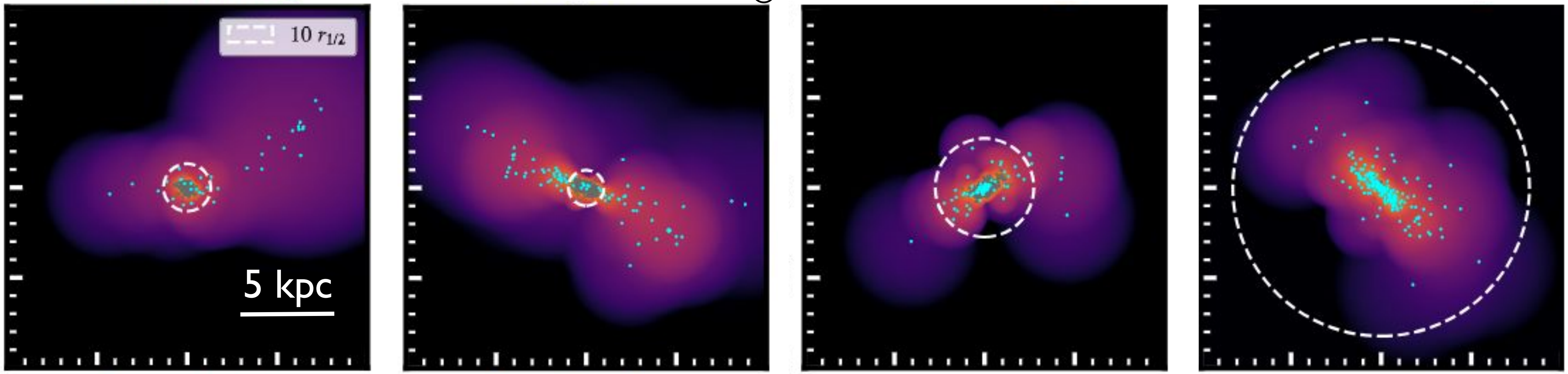

earlier forming ⟷ later forming

Could these help constrain DM models where halos evolve unlike CDM?

later formers have:
- lower stellar mass
- stars mainly accreted (vs formed insitu)
- larger galaxy size (circles = 10 half-light radii)
- more elliptical
- lower metallicity

Rey+ 2019, Goater+, incl SYK 2023

what underlies these trends?

The star formation rate correlates with the central density.

SYK+ 2024 (arXiv:2408.15214),
Read+ 2017, Posti+ 2019, & others

what underlies these trends? | DarkLight

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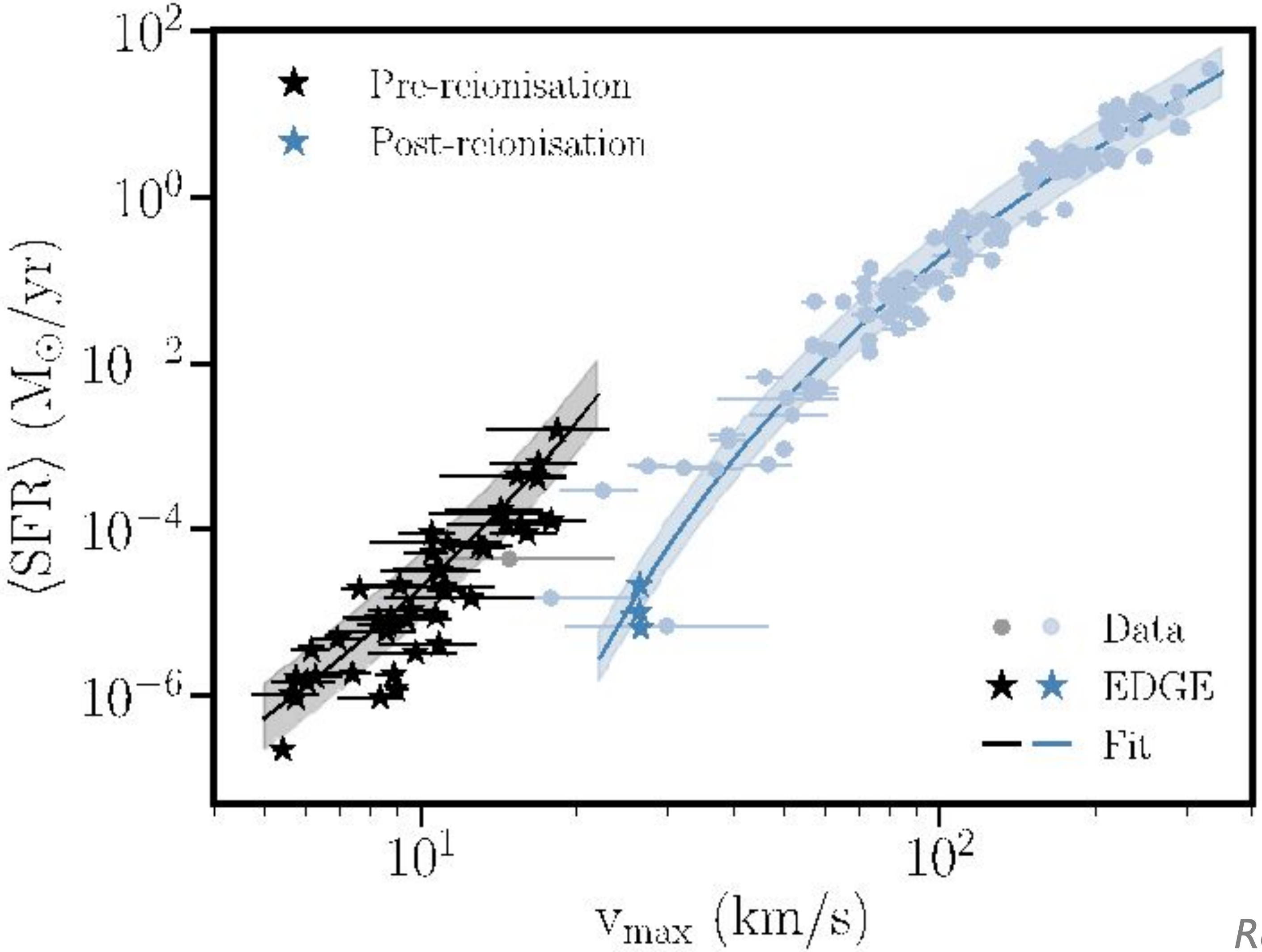

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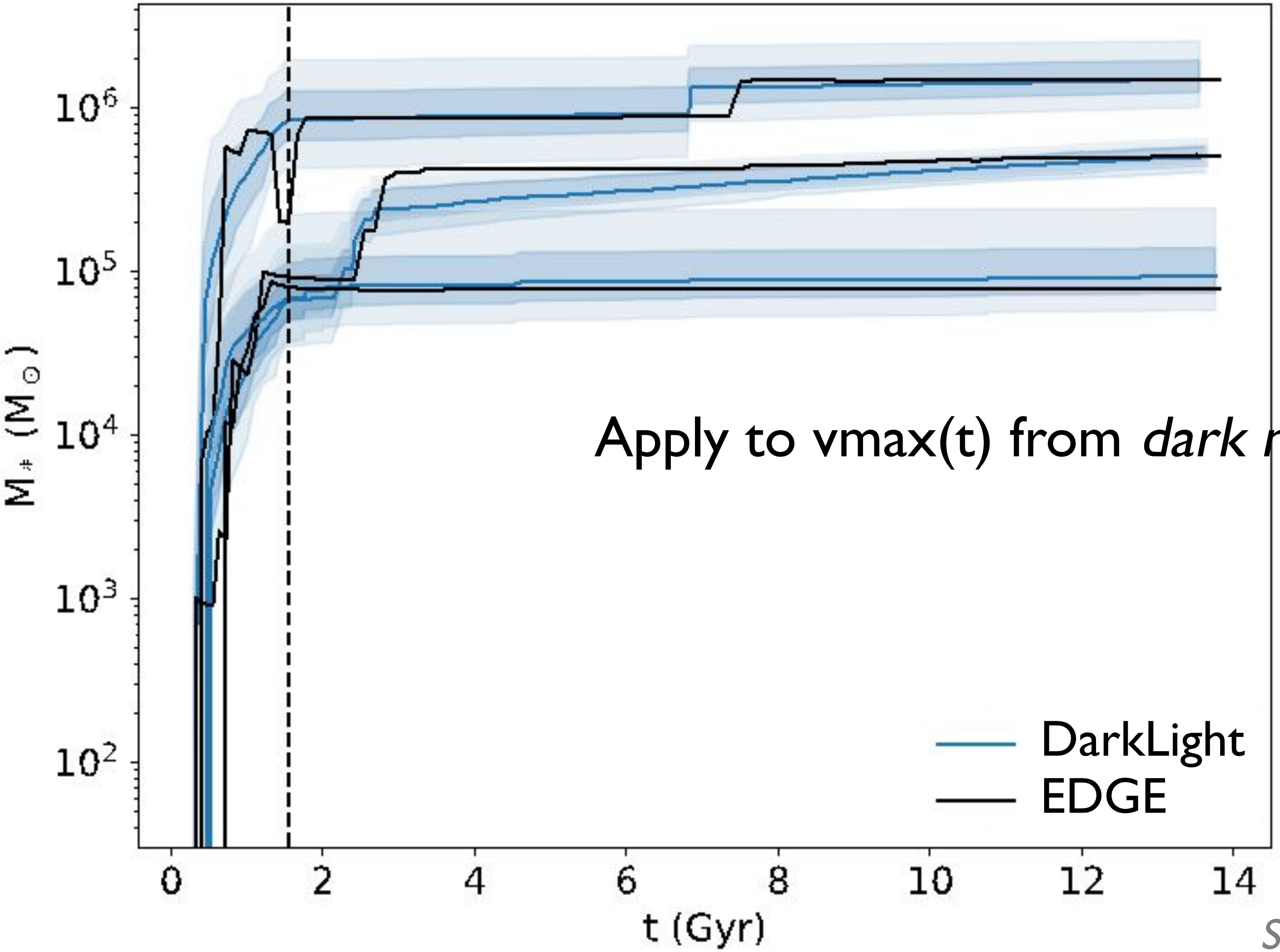

Apply to vmax(t) from *dark matter only* sims.

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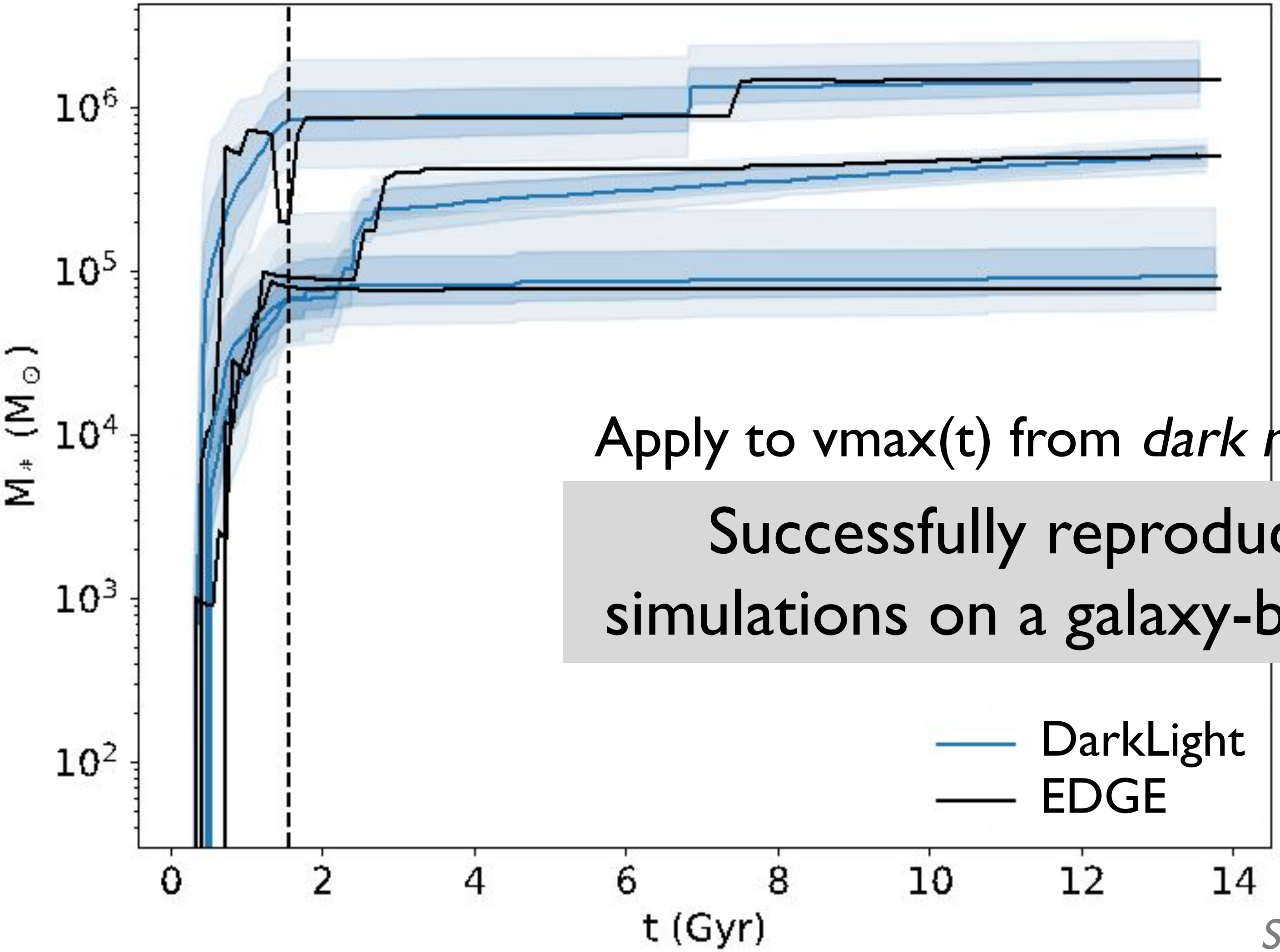


Apply to vmax(t) from *dark matter only* sims.

Successfully reproduces baryon simulations on a galaxy-by-galaxy basis!

SYK+ 2024 (arXiv:2408.15214)

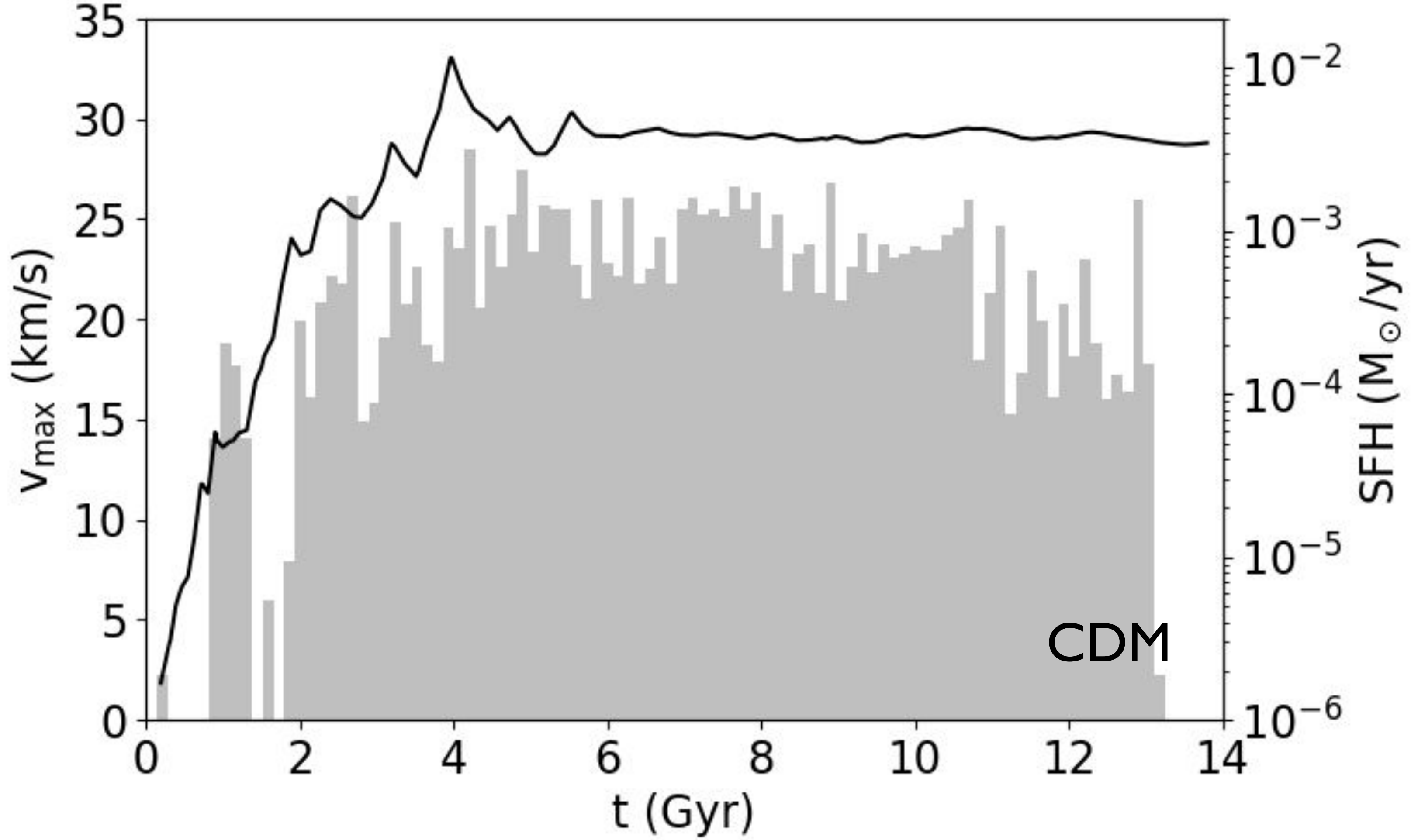
implications for dark matter

SFHs and M_* differ in models with different central densities or growth histories.

SYK+, in prep

implications for dark matter | WDM

SFHs and M_* differ in models with different central densities or growth histories. For example, in WDM:



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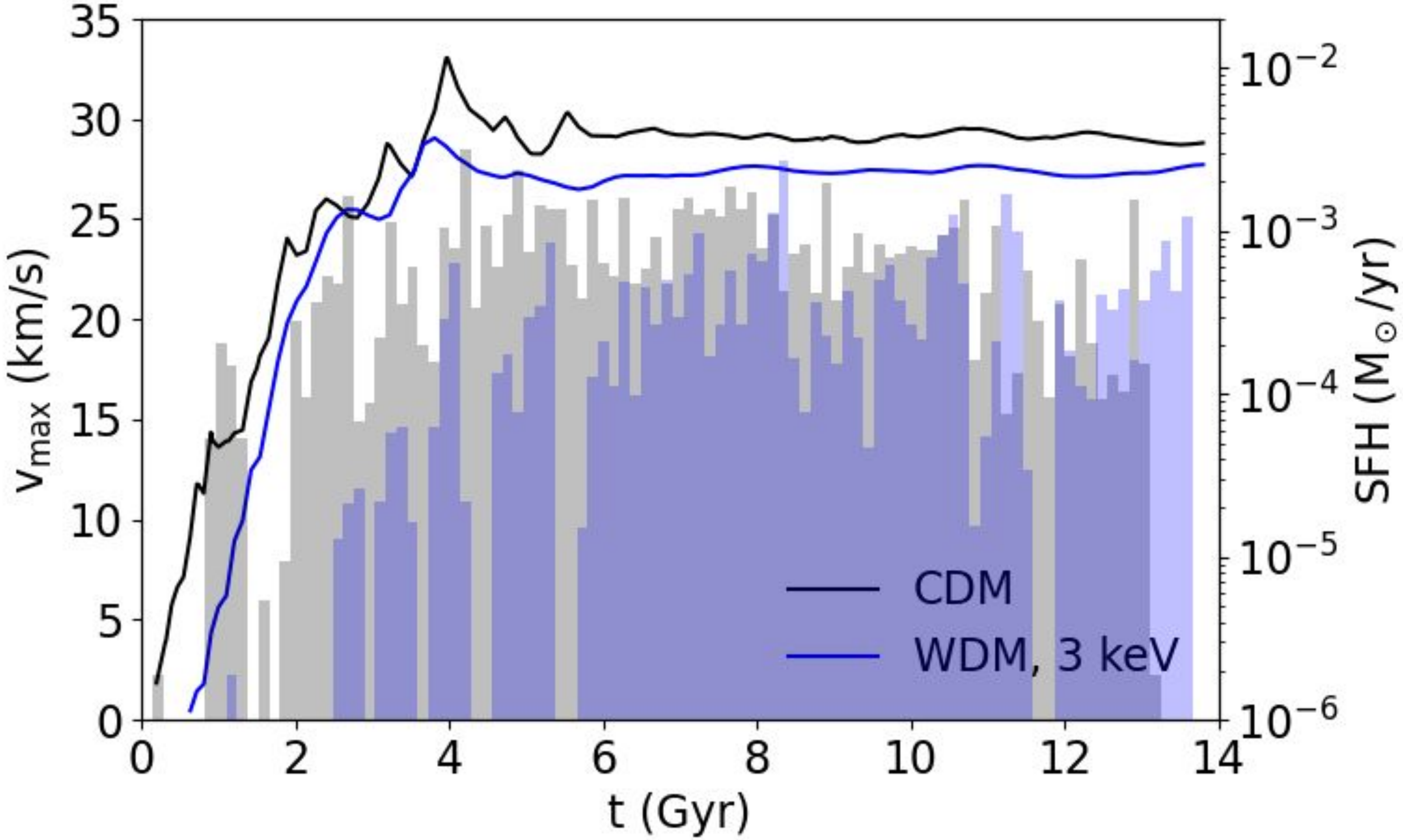

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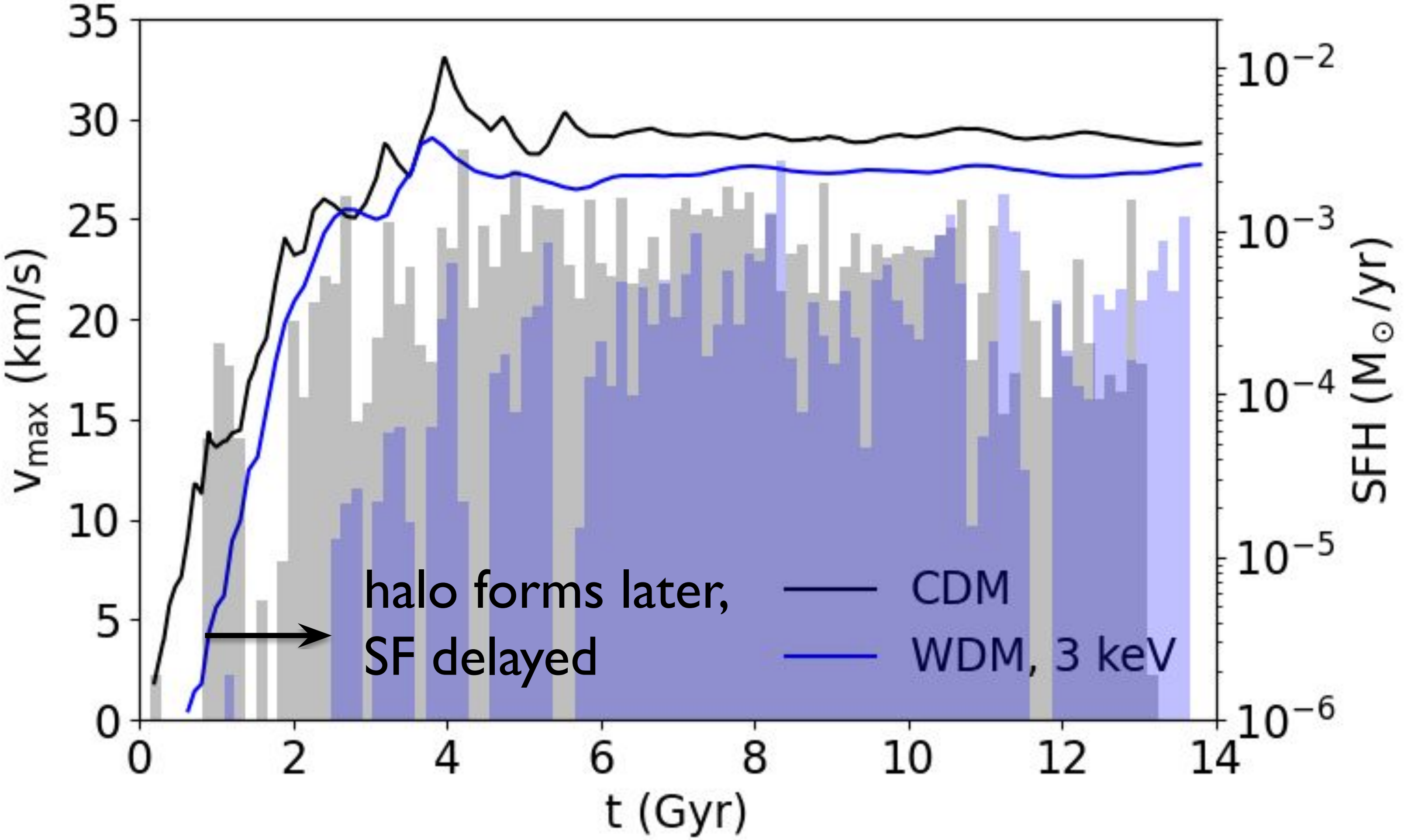

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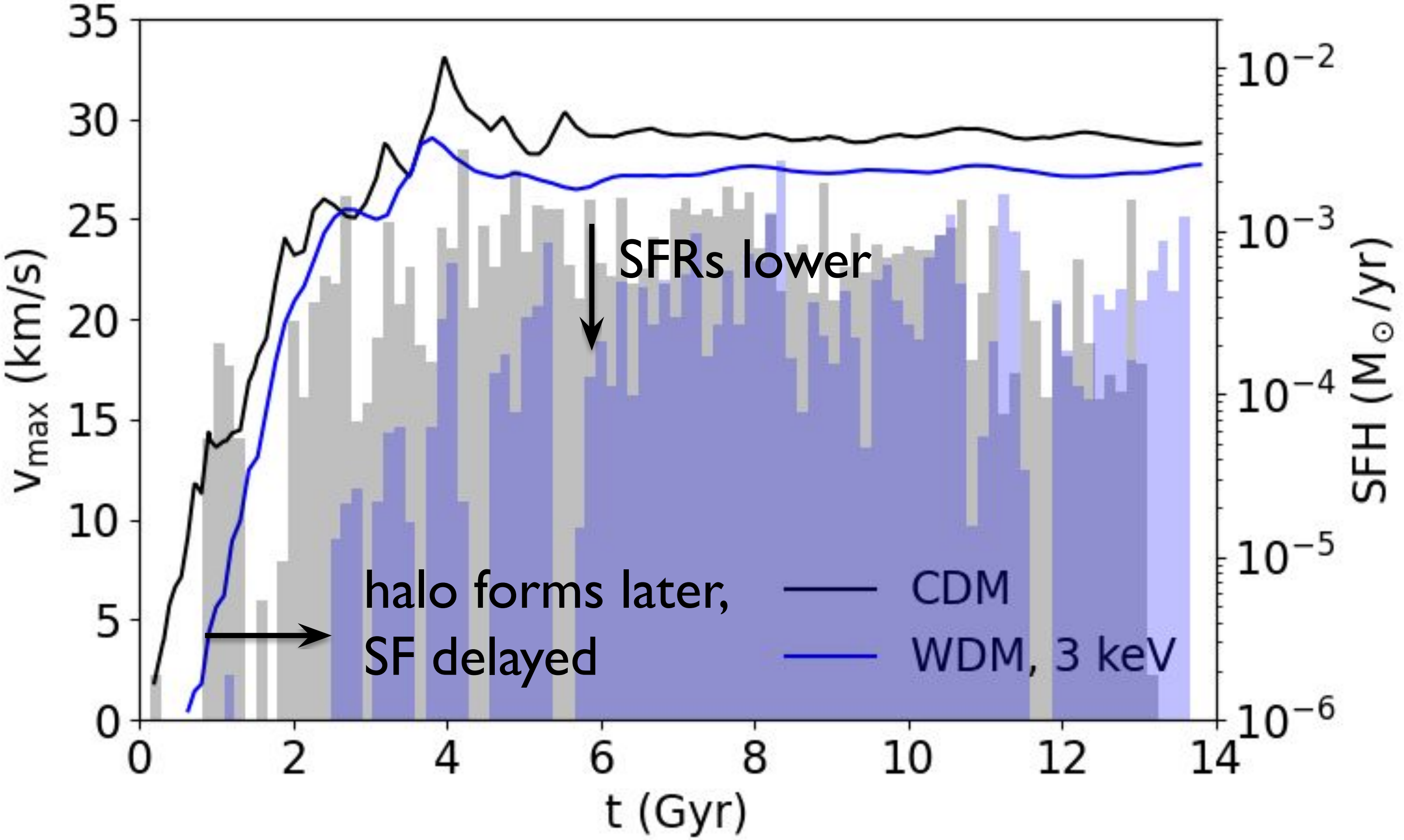

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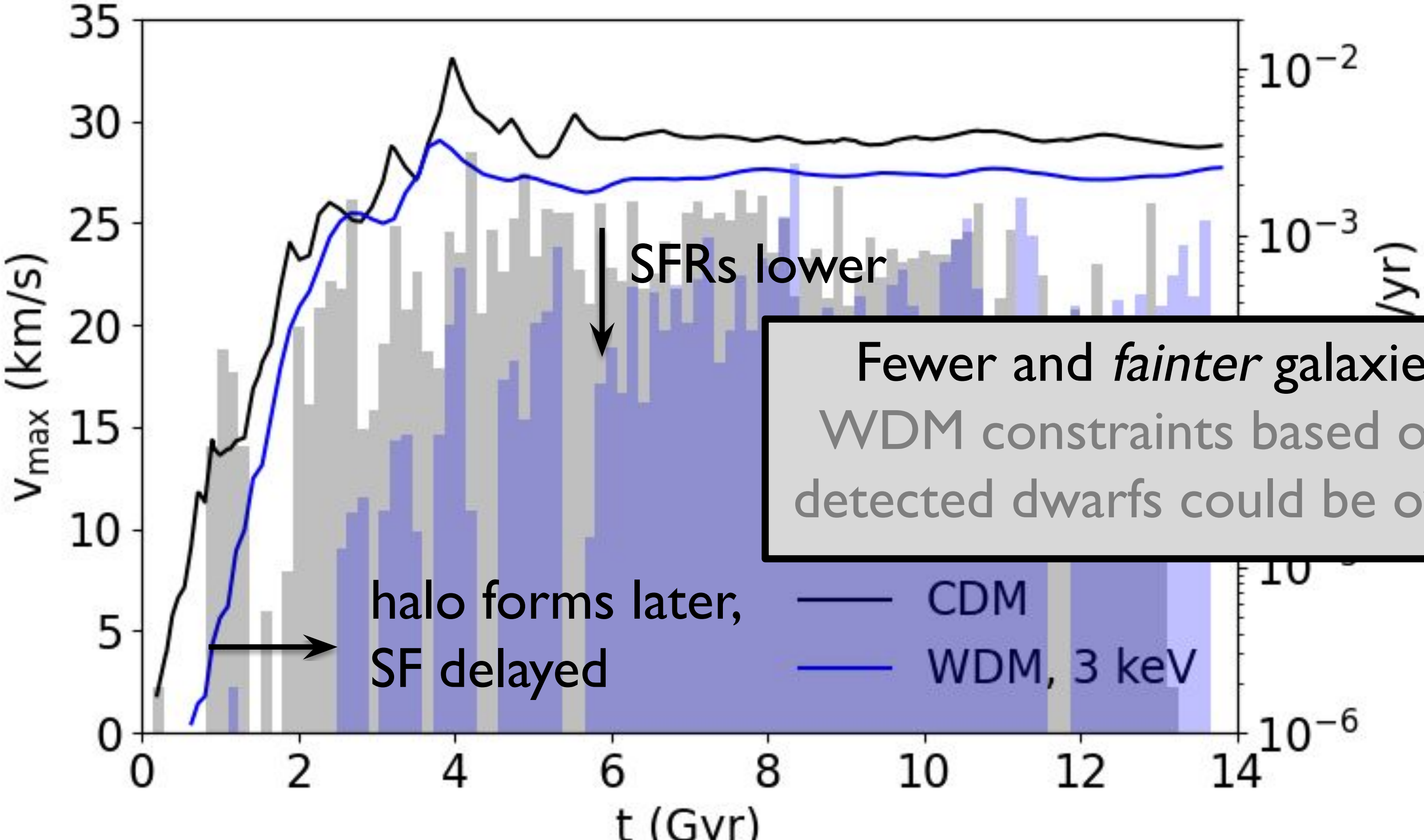
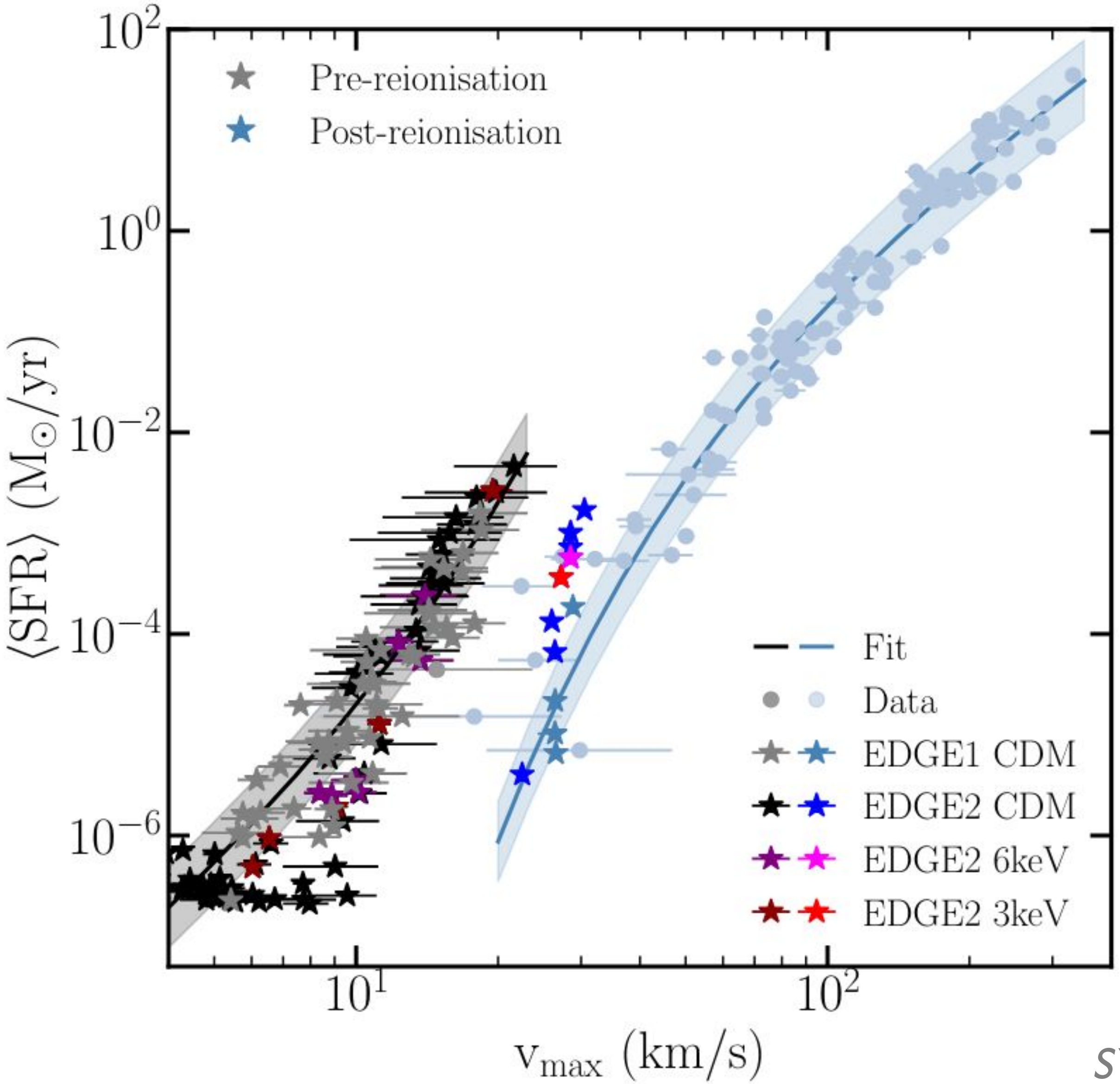


Fewer and *fainter* galaxies in WDM!
WDM constraints based on number of detected dwarfs could be overestimated?

SYK+, in prep

how universal is galaxy formation?



DarkLight's relation between star formation rates and v_{max} potentially universal?

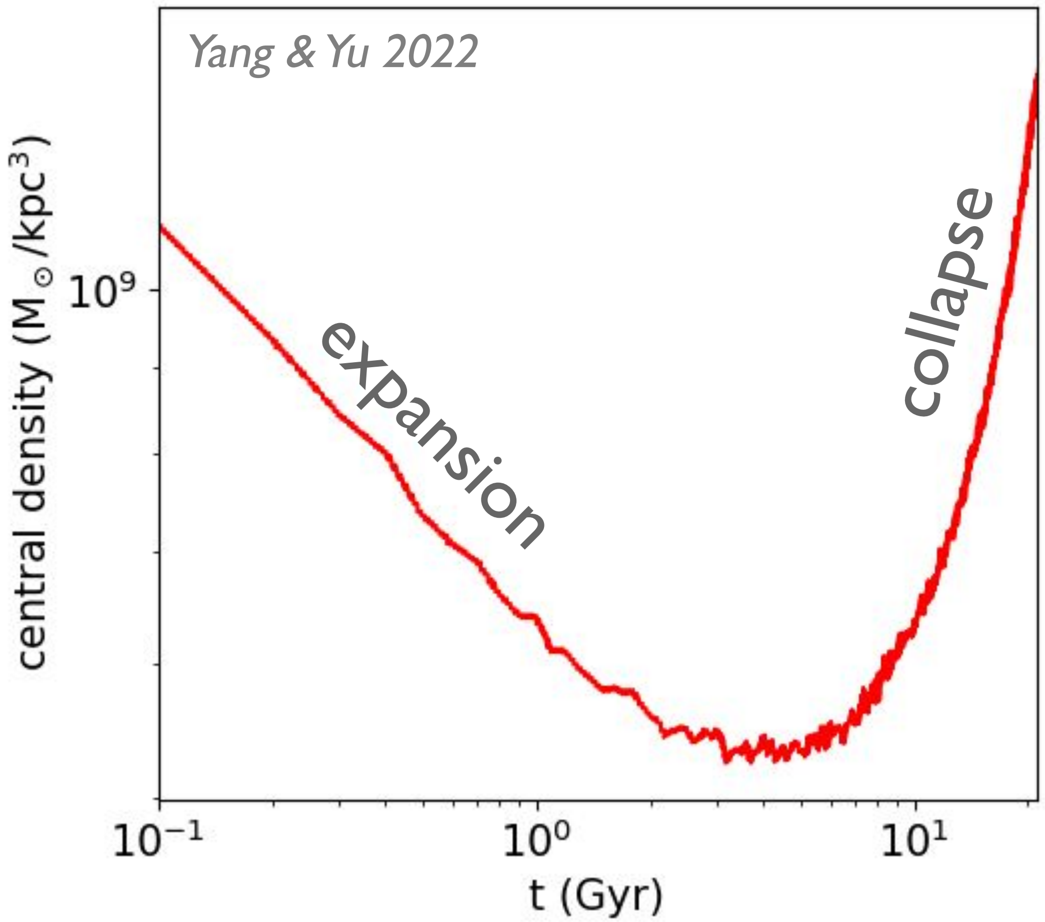
Captures behavior in EDGE simulations with CDM and WDM.

Testing if this works in SIDM!

SYK+, in prep, see also see Kim+ 2024 (arXiv:2408.15214)

implications for SIDM | star formation histories

SFHs and M_* differ in models with different central densities or growth histories.



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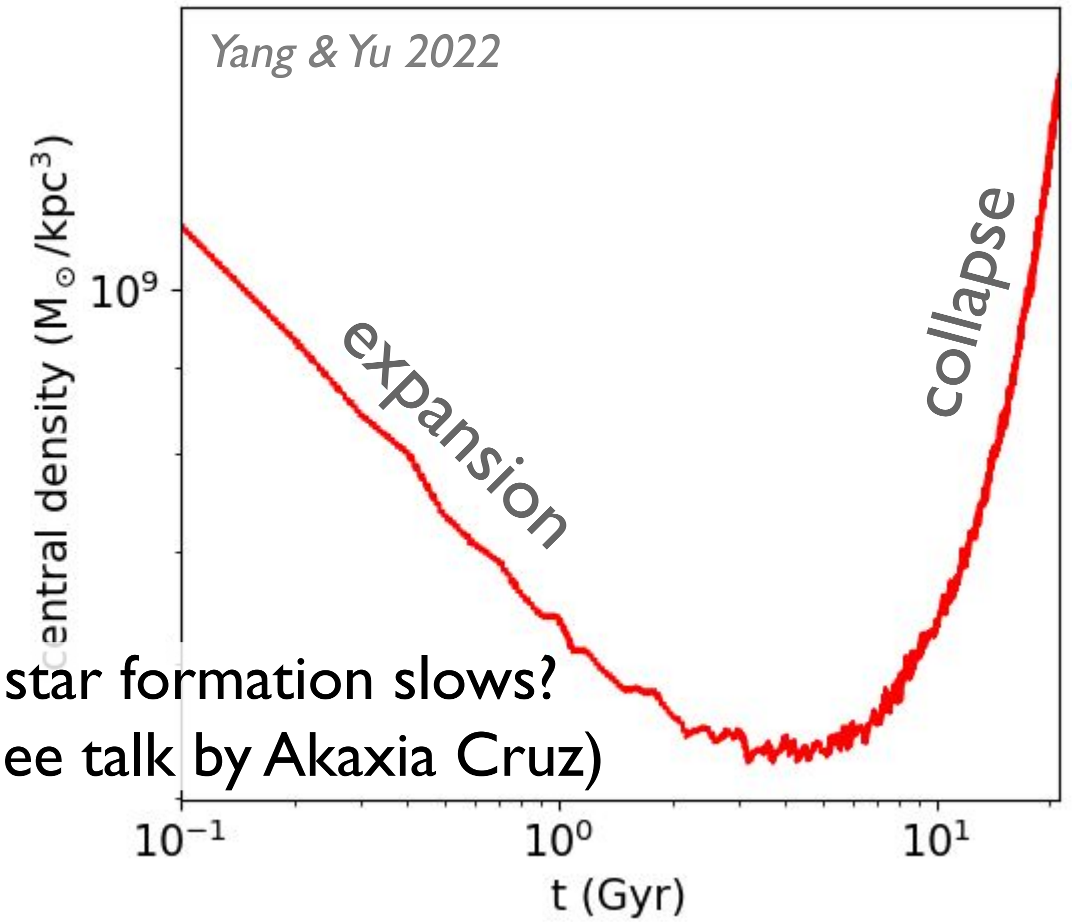
SFHs and M_* differ in models with different central densities or growth histories.
Star formation stochasticity results in scatter, but general trends expected:



star formation slows?
(see talk by Akaxia Cruz)

implications for SIDM | star formation histories

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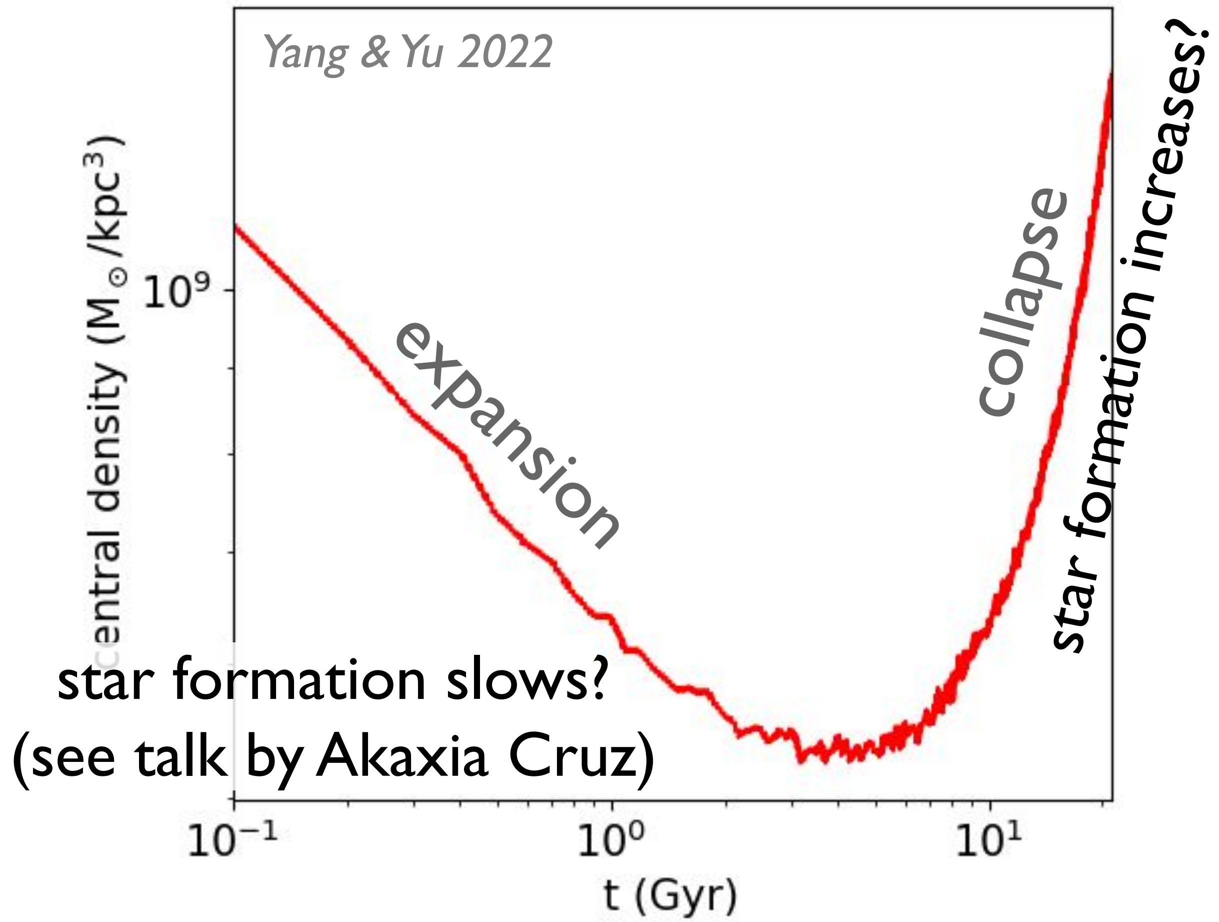

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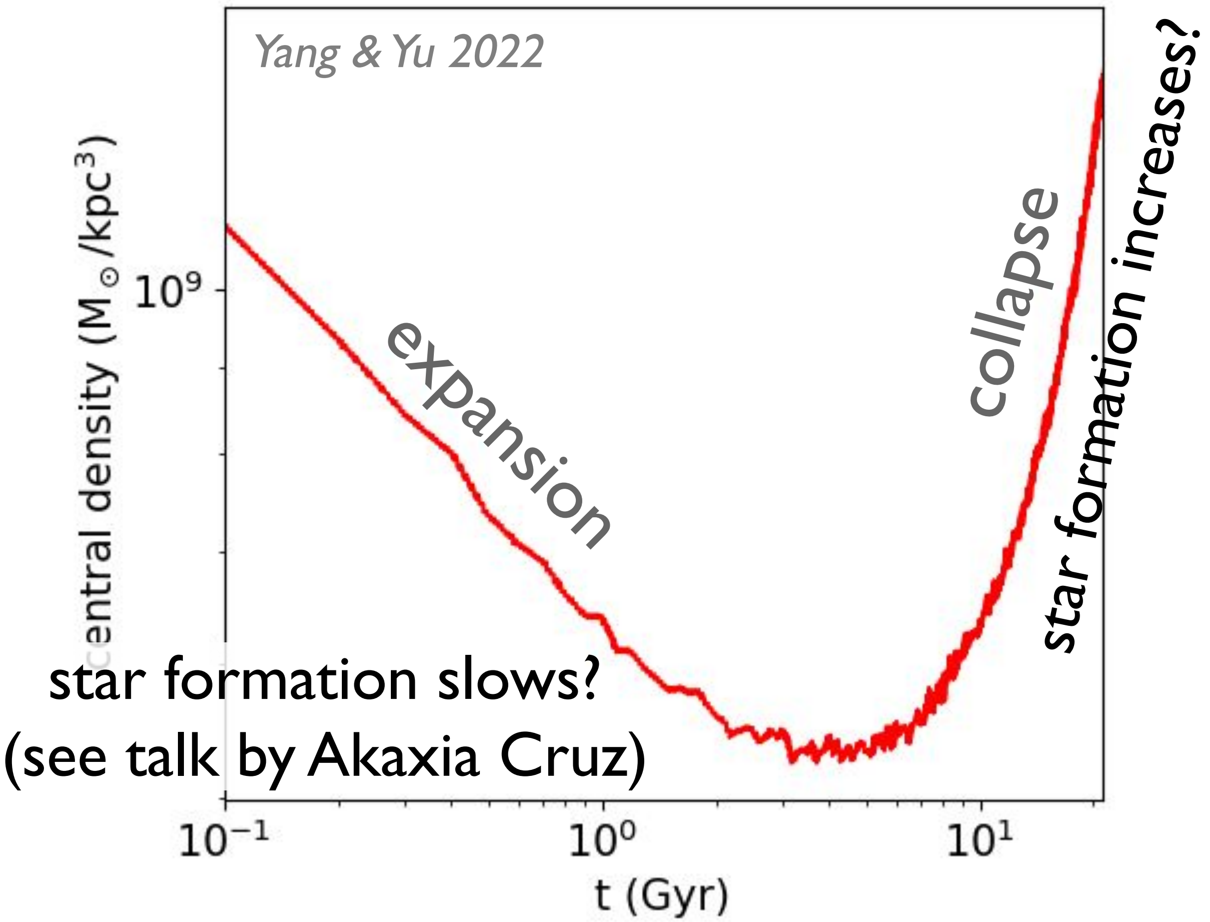

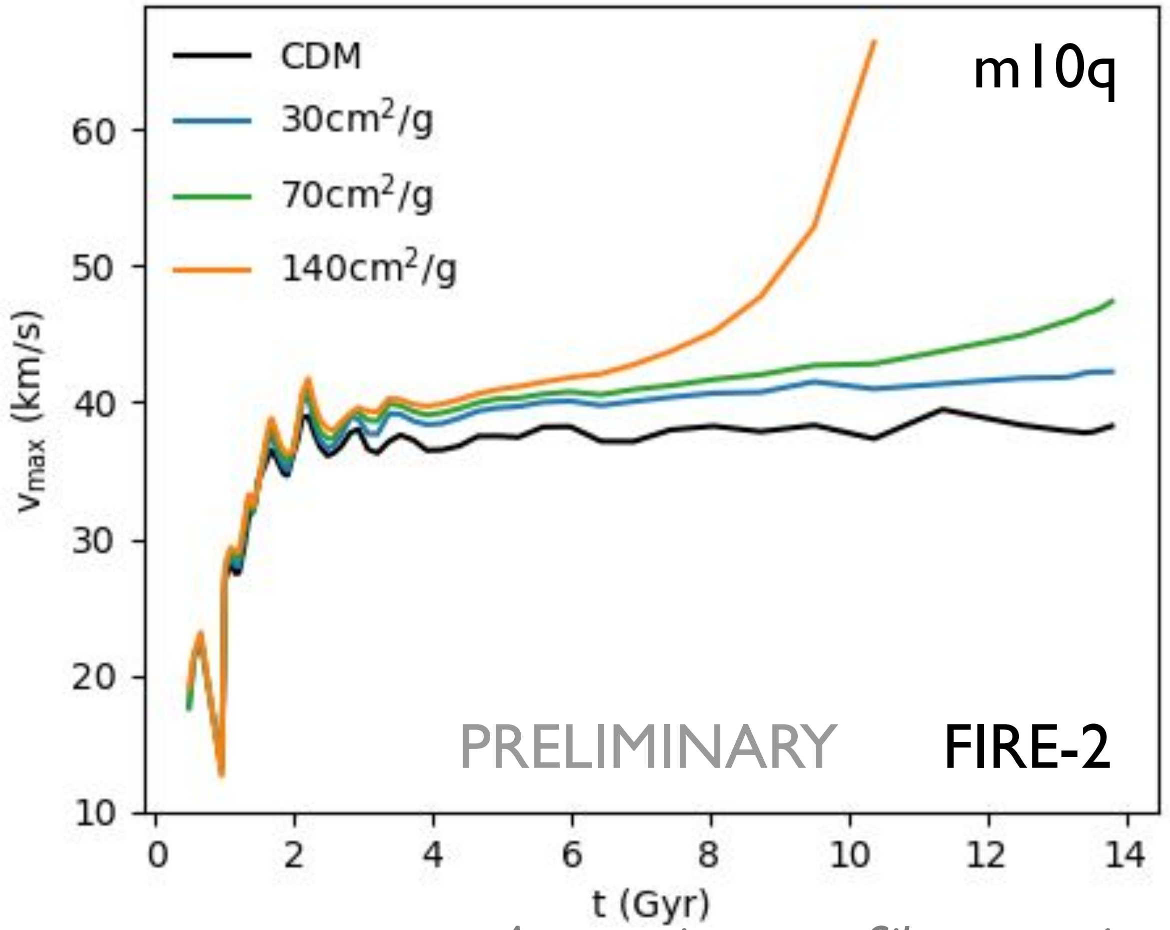

Arora, priv. comm., Silverman+, in prep.

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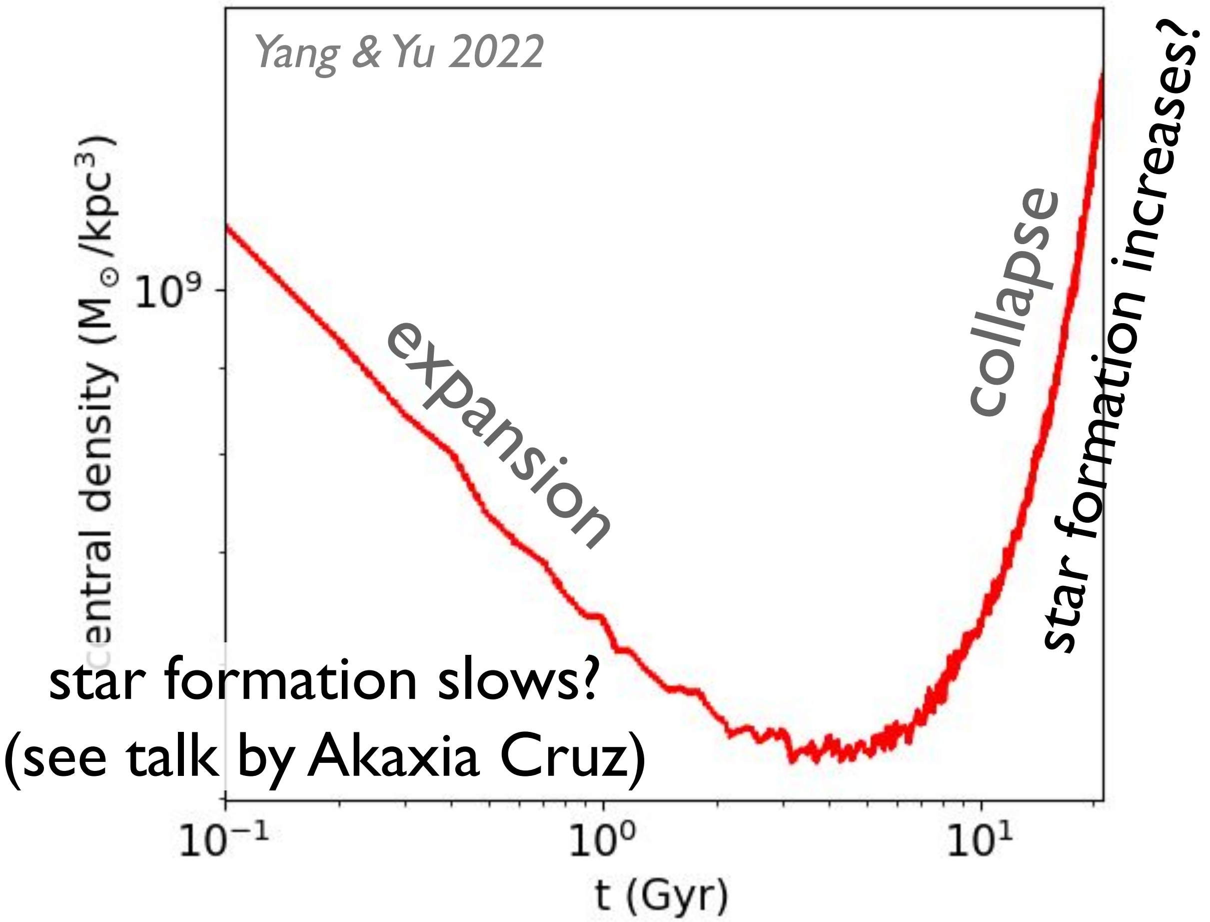

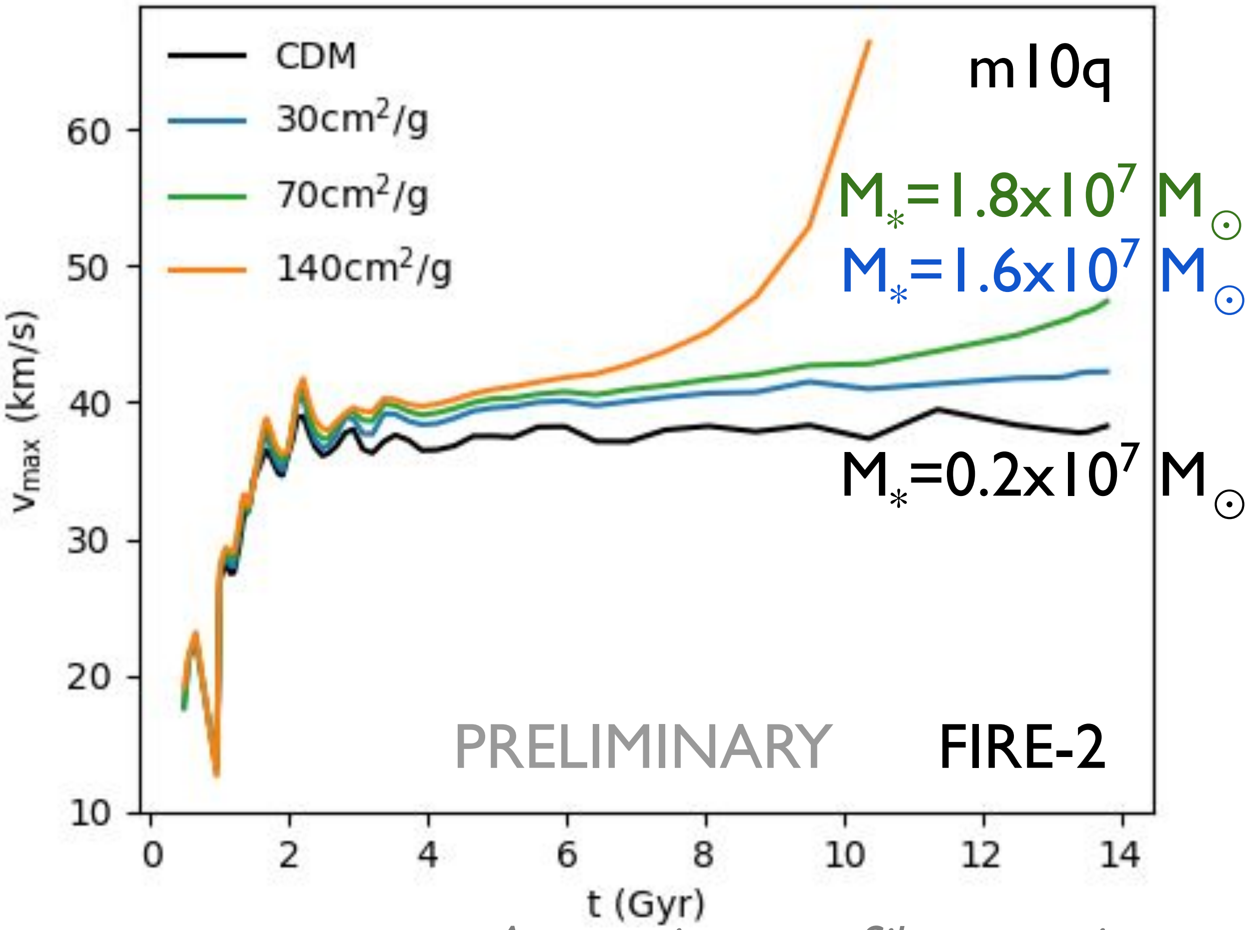

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implications for SIDM | deep core collapse

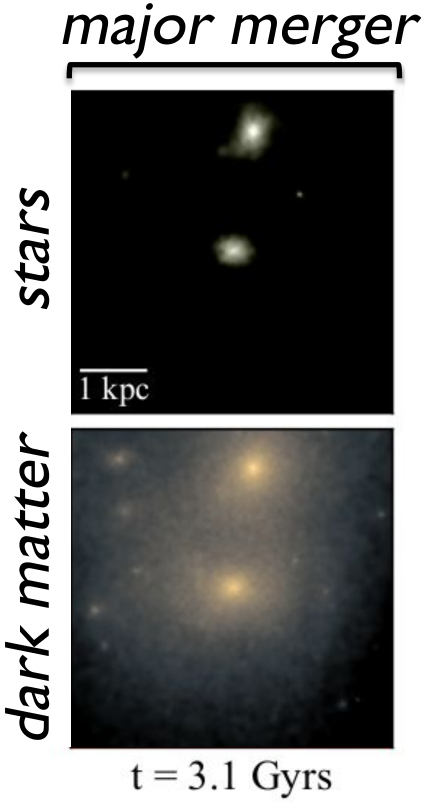
Star formation quenching deep in core collapse? Gas is finite!

implications for SIDM | deep core collapse

Izzy Gray

Star formation quenching deep in core collapse? Gas is finite!

A potential analog in CDM:



Grey et al, incl. SYK 2024

implications for SIDM | deep core collapse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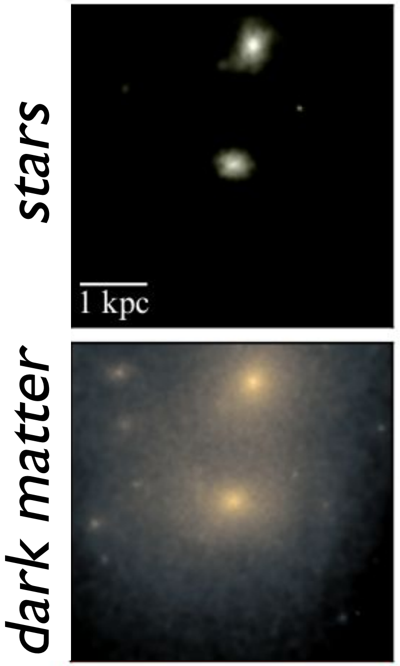
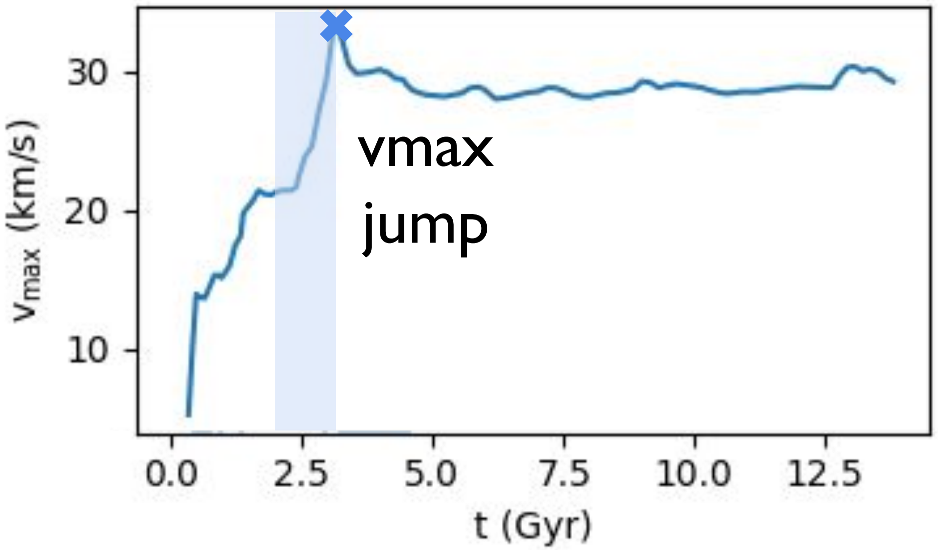
A potential analog in CDM:

major merger



t = 3.1 Gyrs



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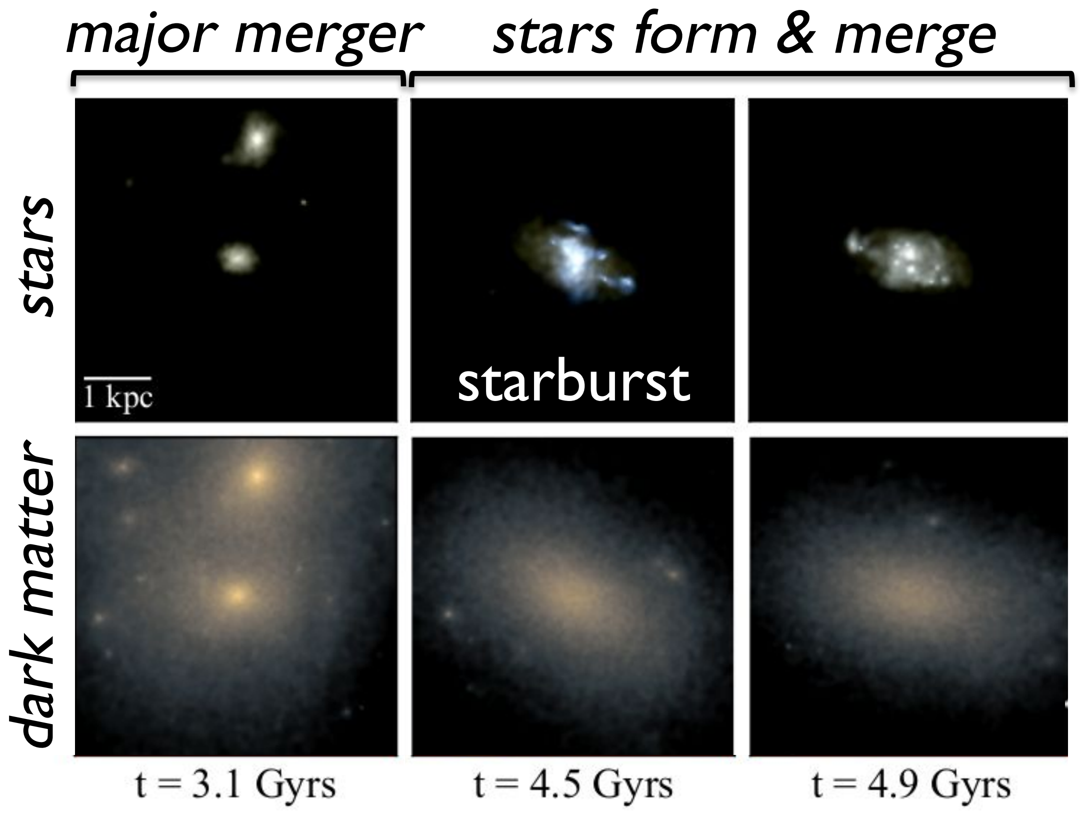

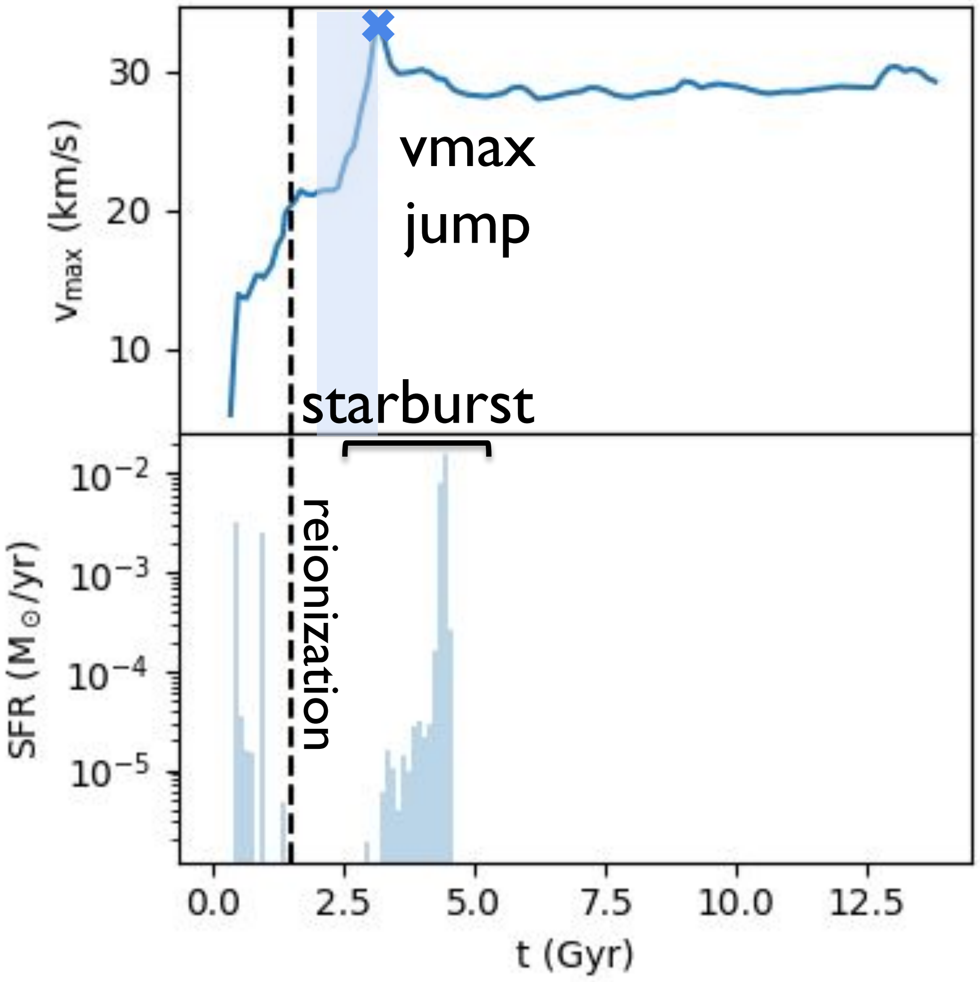

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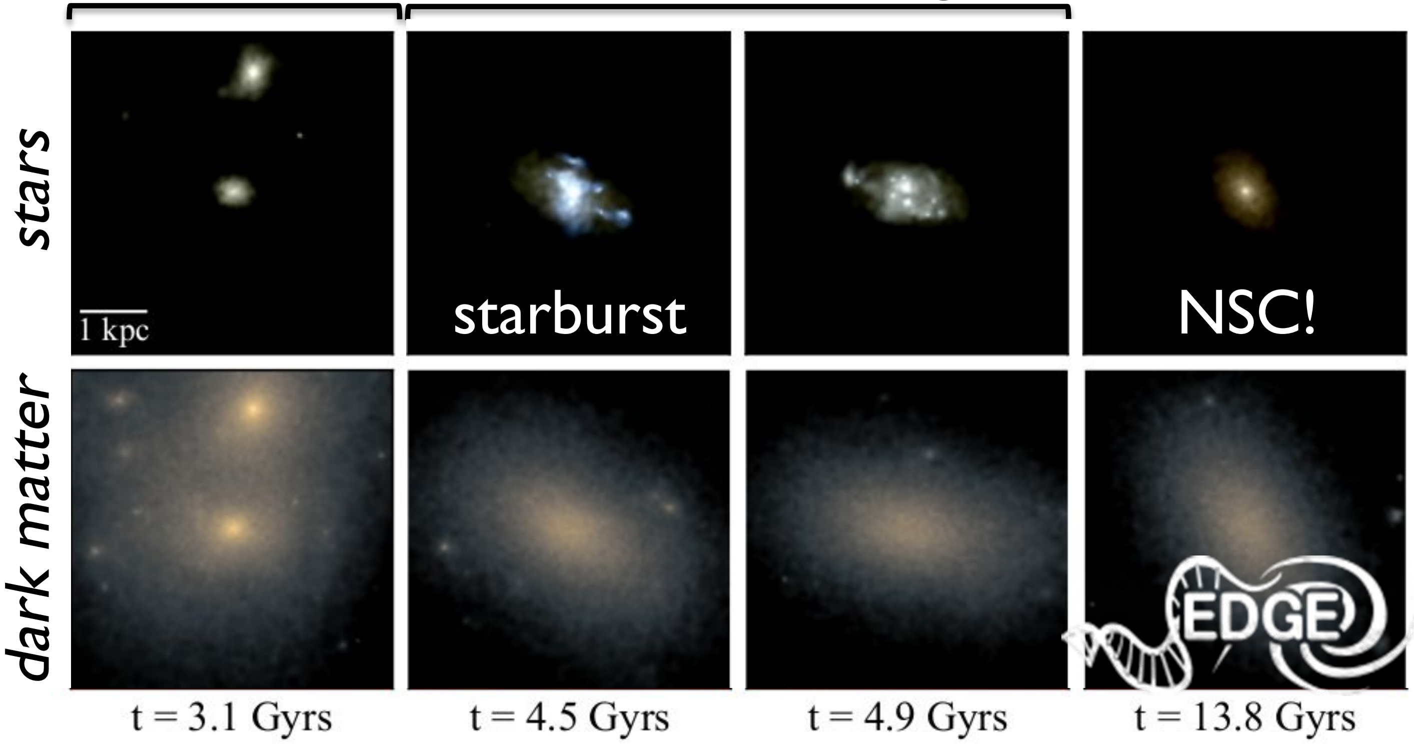
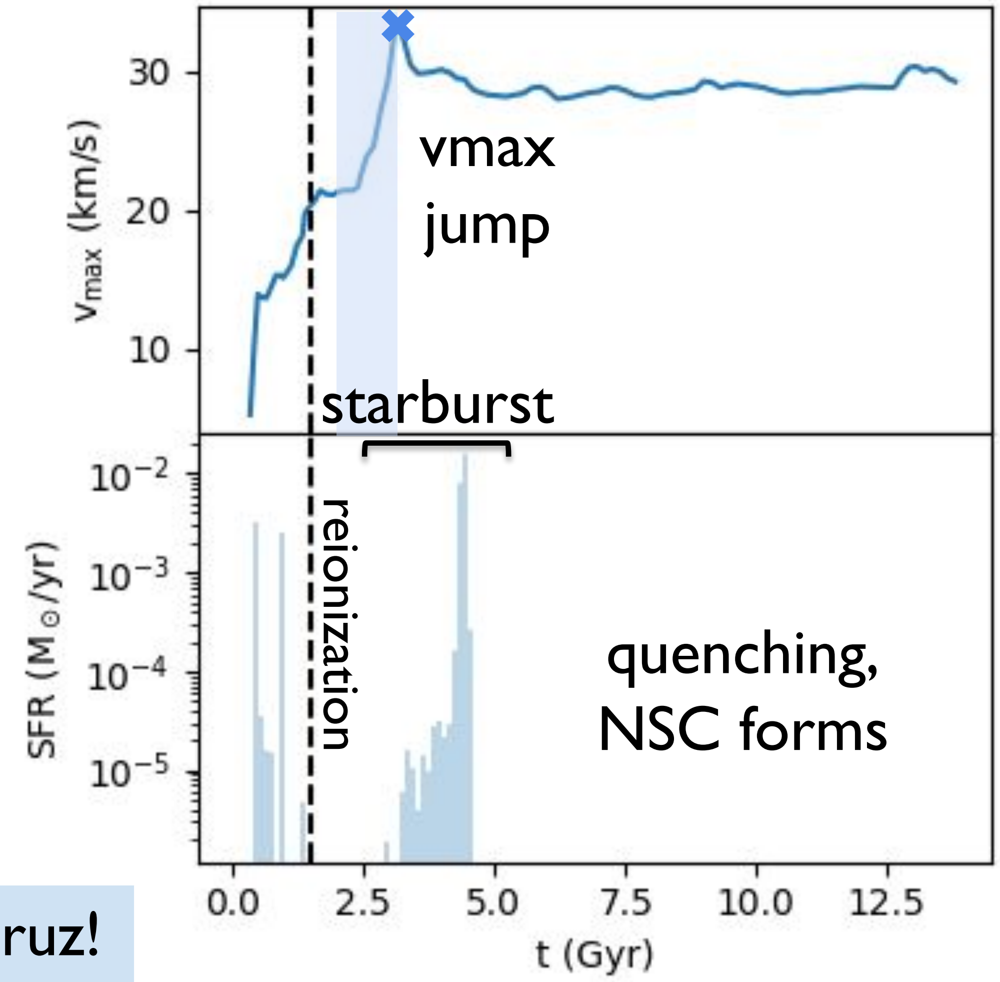




In SIDM: see talk by Akaxia Cruz!

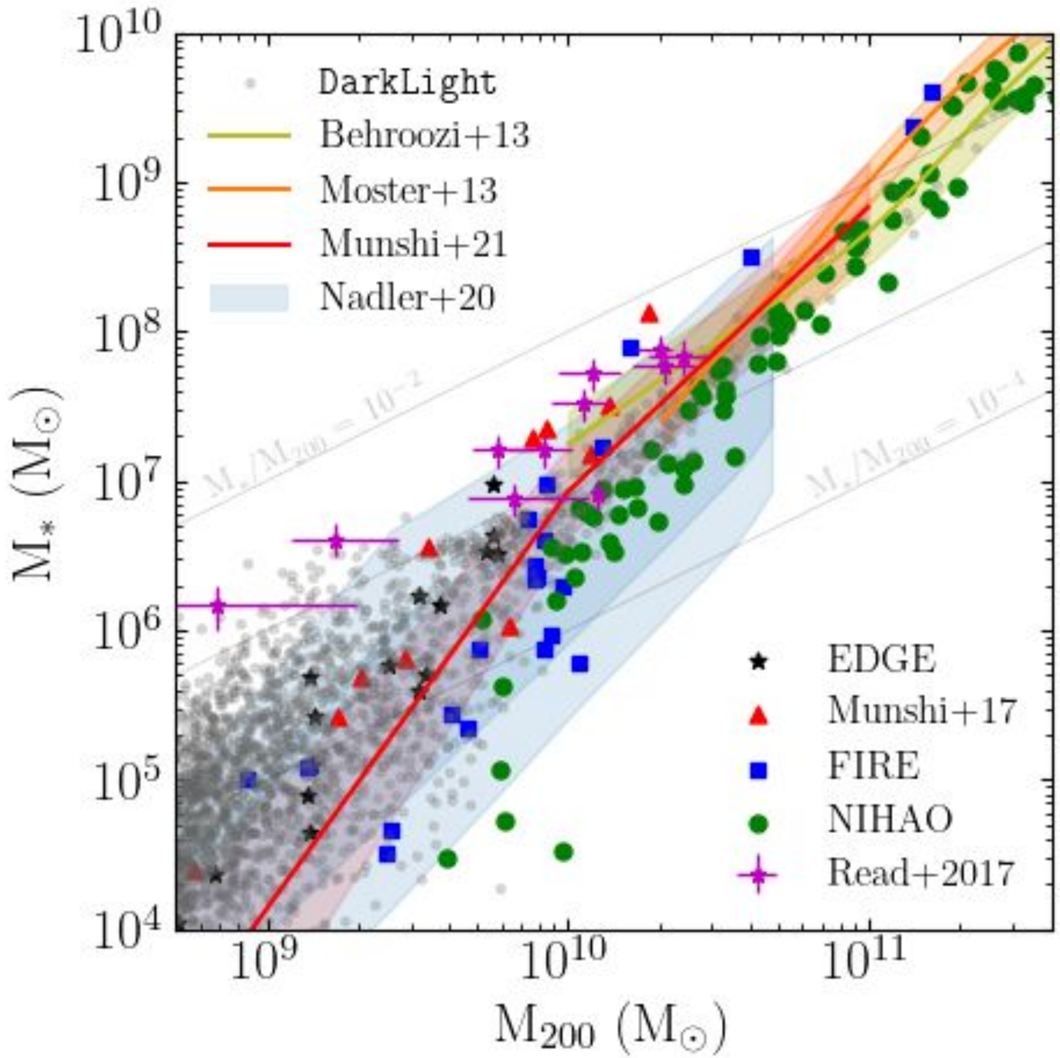
Grey et al, incl. SYK 2024

implications for SIDM | scaling relations

Changes in the stellar-mass–halo-mass (SMHM) relation?

DarkLight run on ~10^4 isolated halos in CDM DMO void volume.

For more details, see Kim et al. 2024 (2408.15214).



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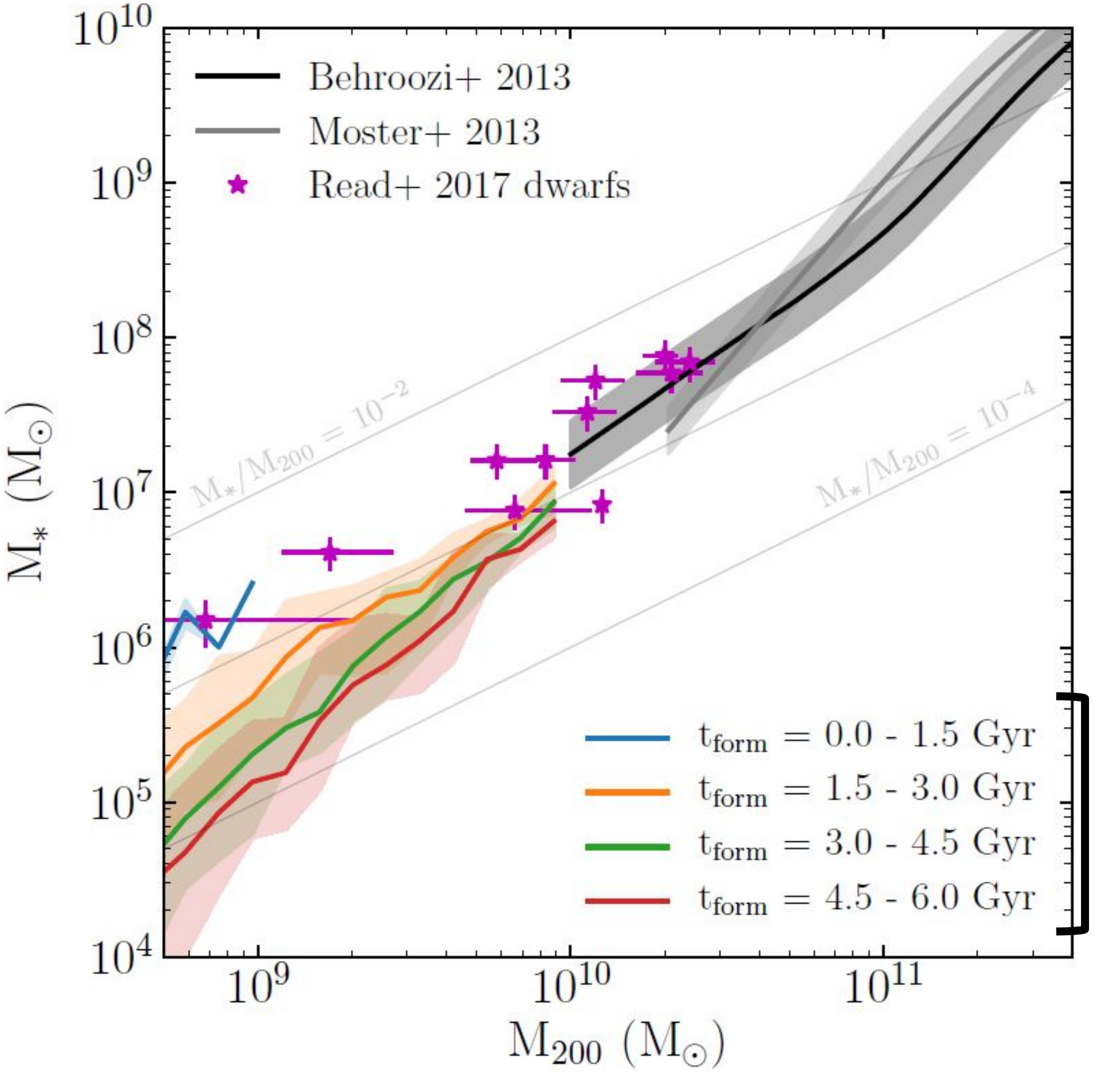

time it took halo to reach 50% of final mass

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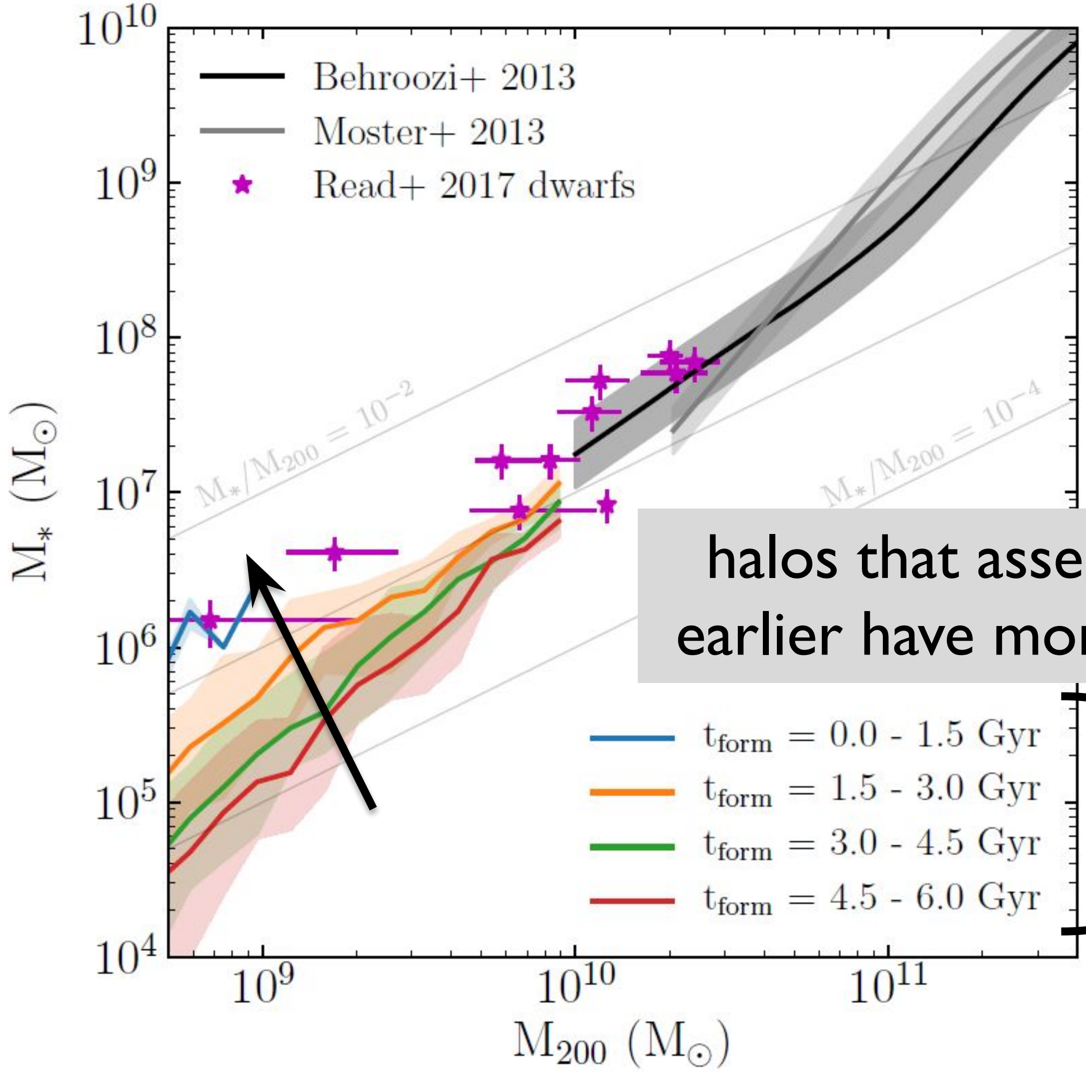

halos that assembled earlier have more stars

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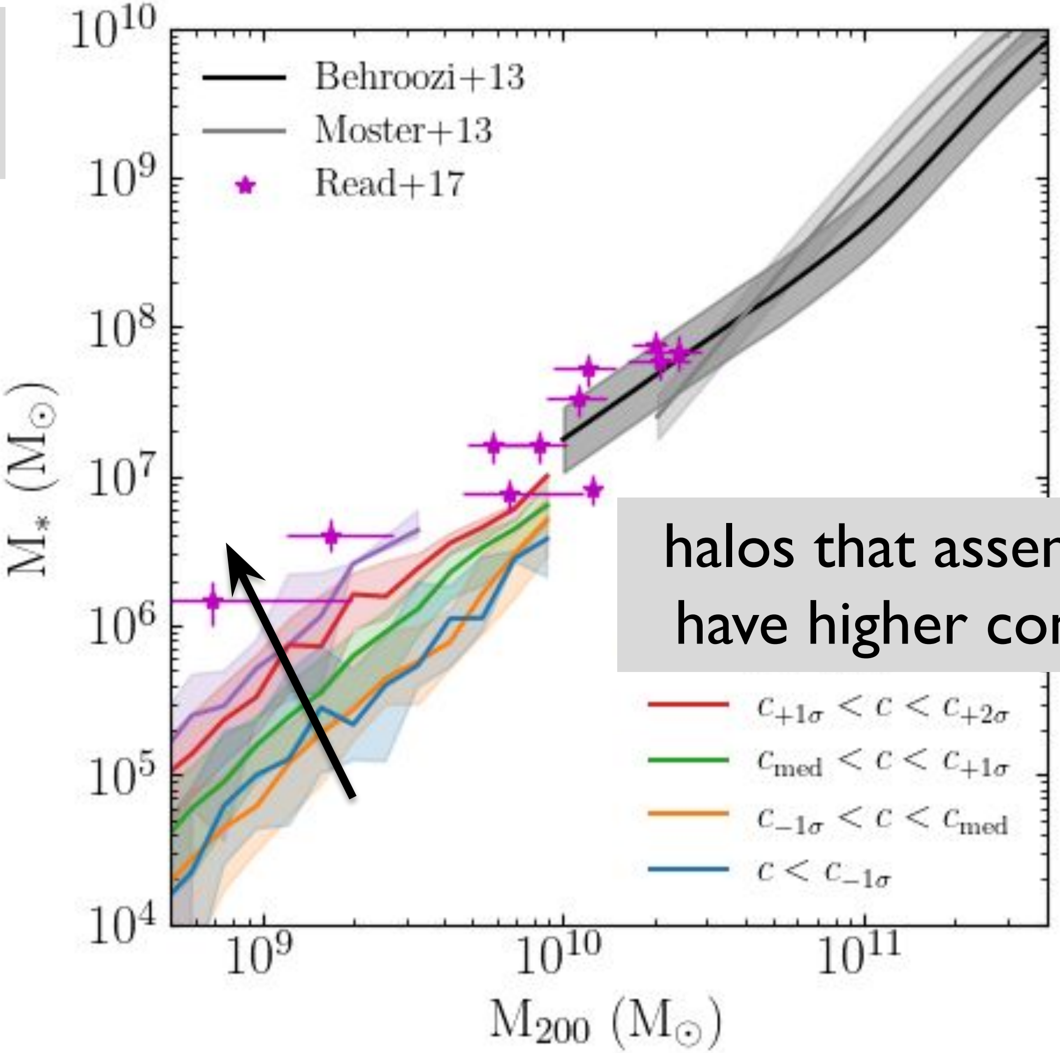
Higher concentration halos collapse faster.



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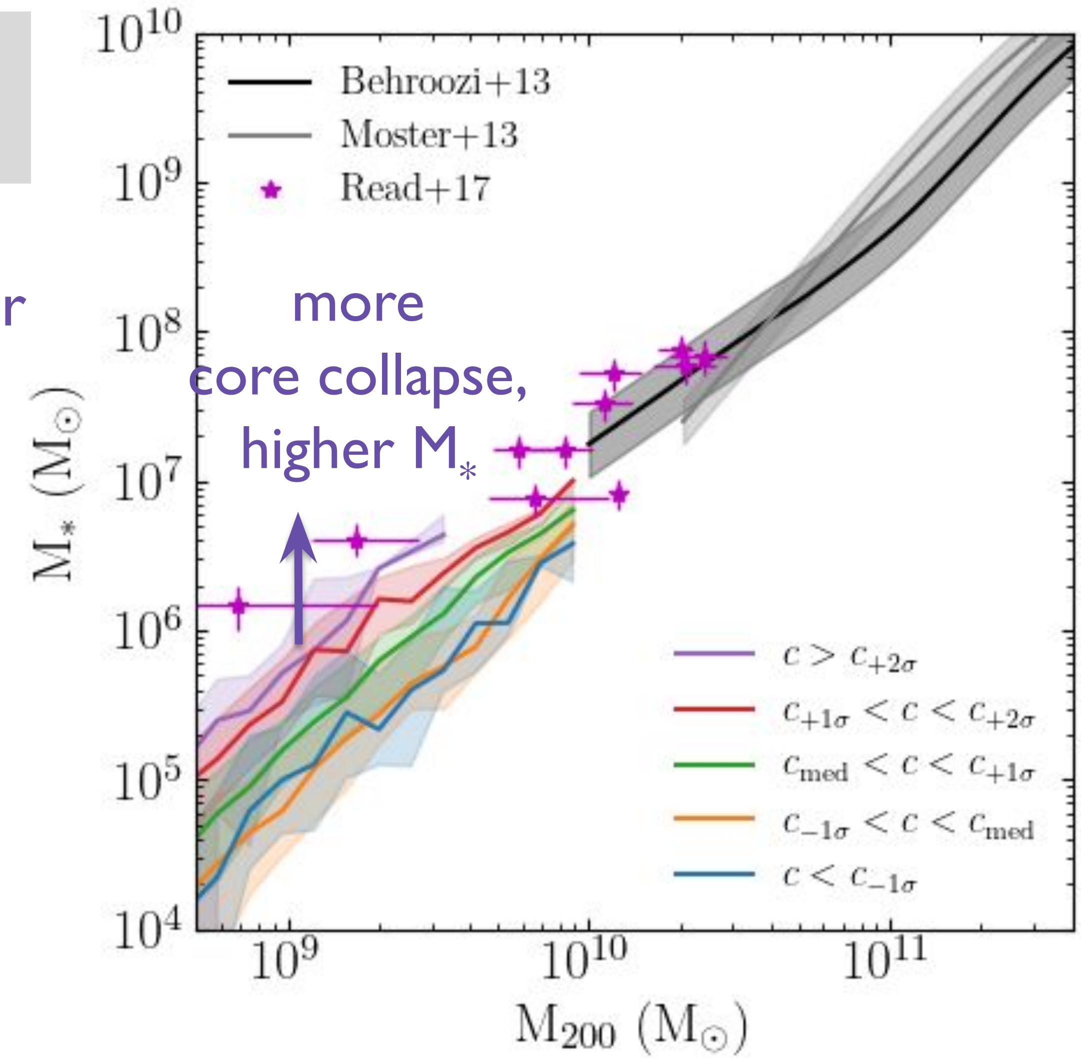
Early formers have higher concentrations, more core collapsed.



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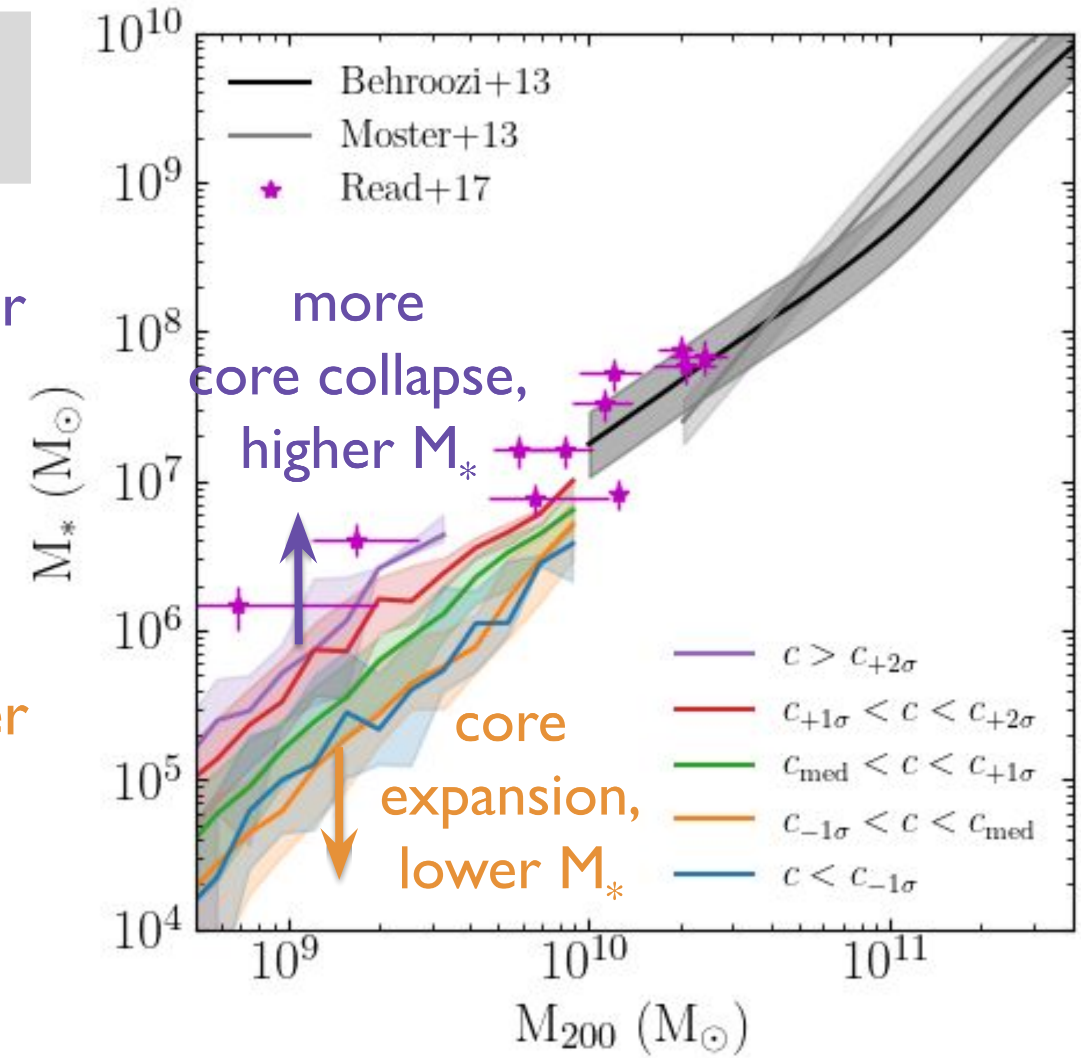
Late formers have lower concentrations, more core expansion.



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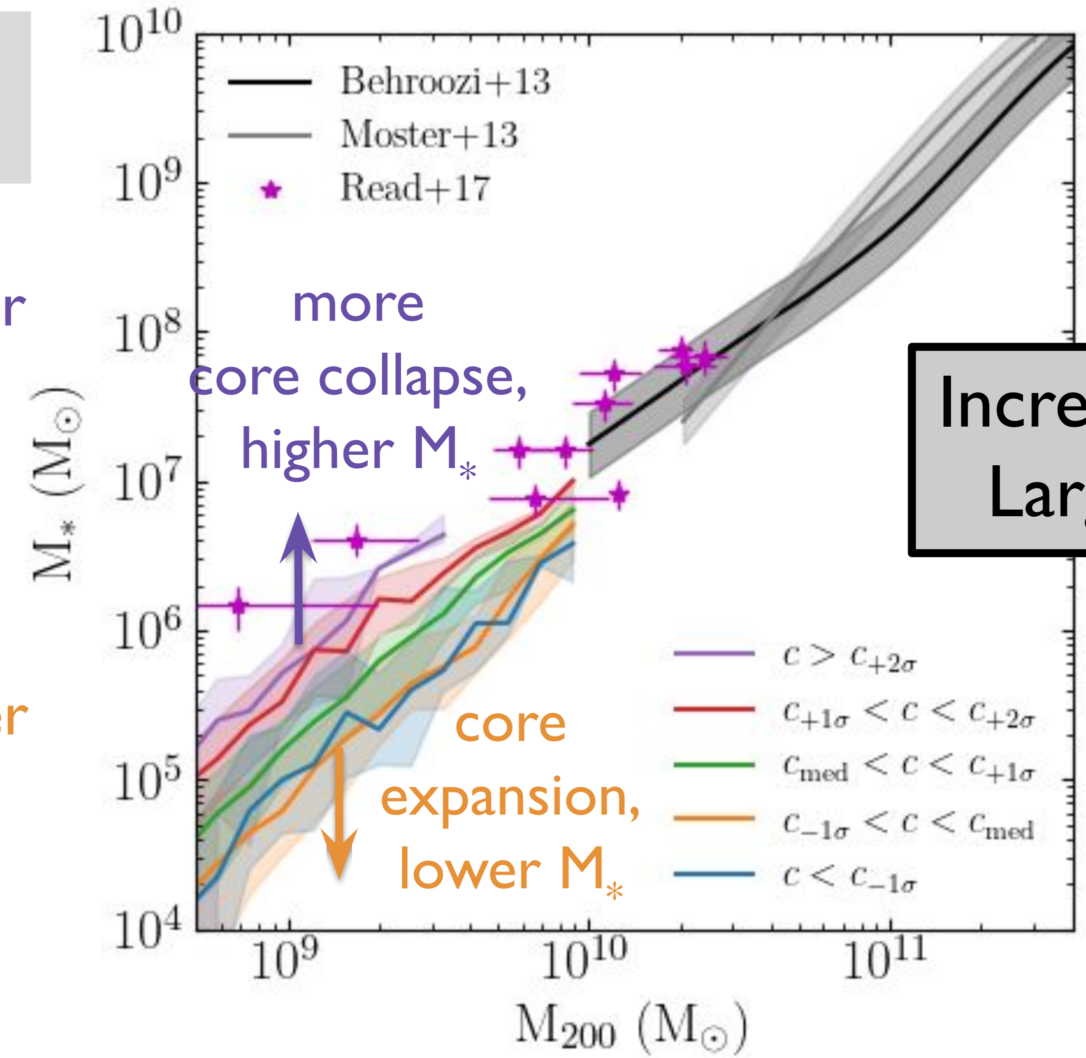


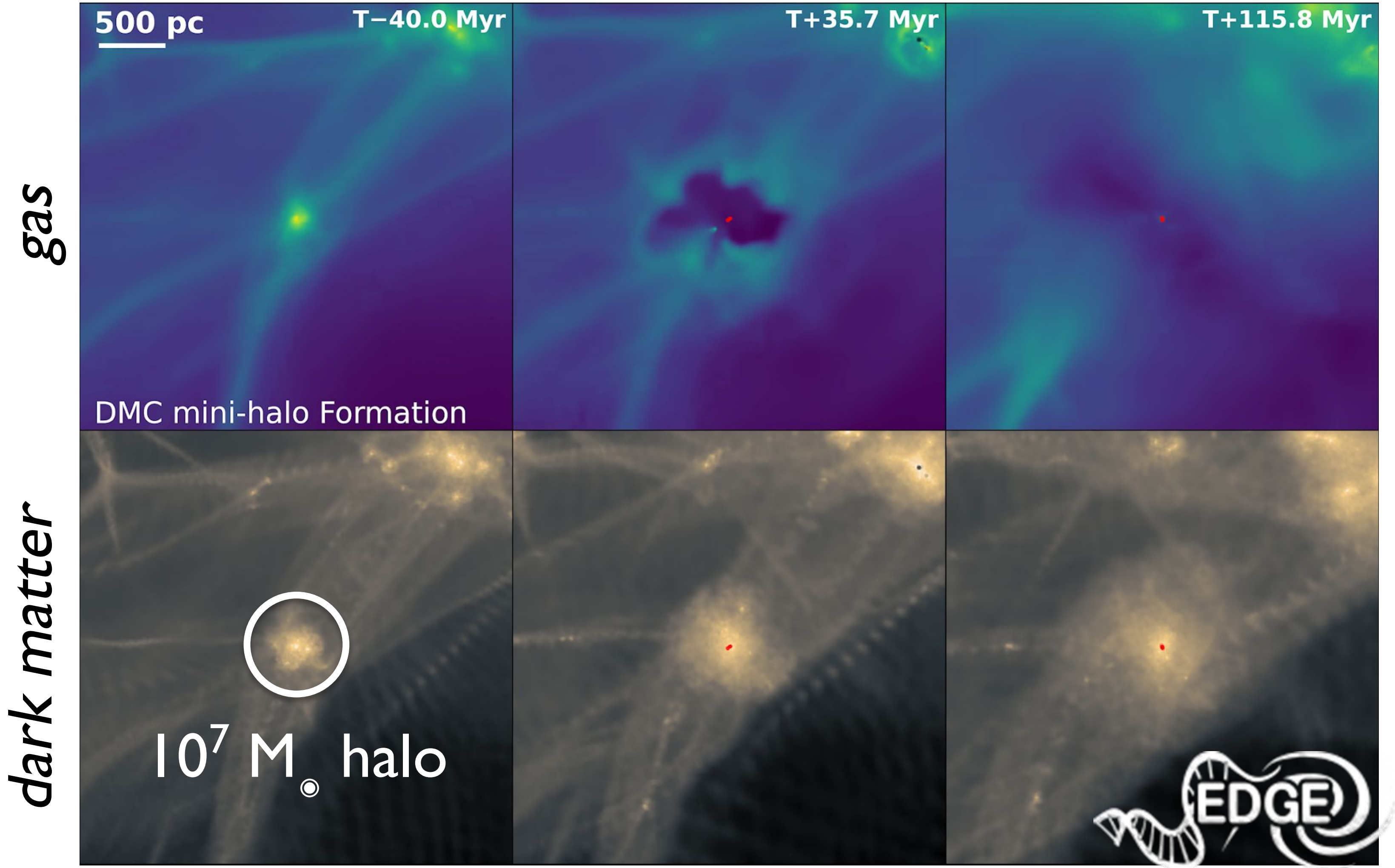
Increased SMHM scatter? Larger diversity in M_*?

CDM SMHM may not be the same in SIDM!

SYK+ 2024 (arXiv:2408.15214)

implications for SIDM | the faintest dwarfs

Ethan Taylor



Taylor, Read, Orkney, SYK+, accepted to Nature

implications for SIDM | the faintest dwarfs

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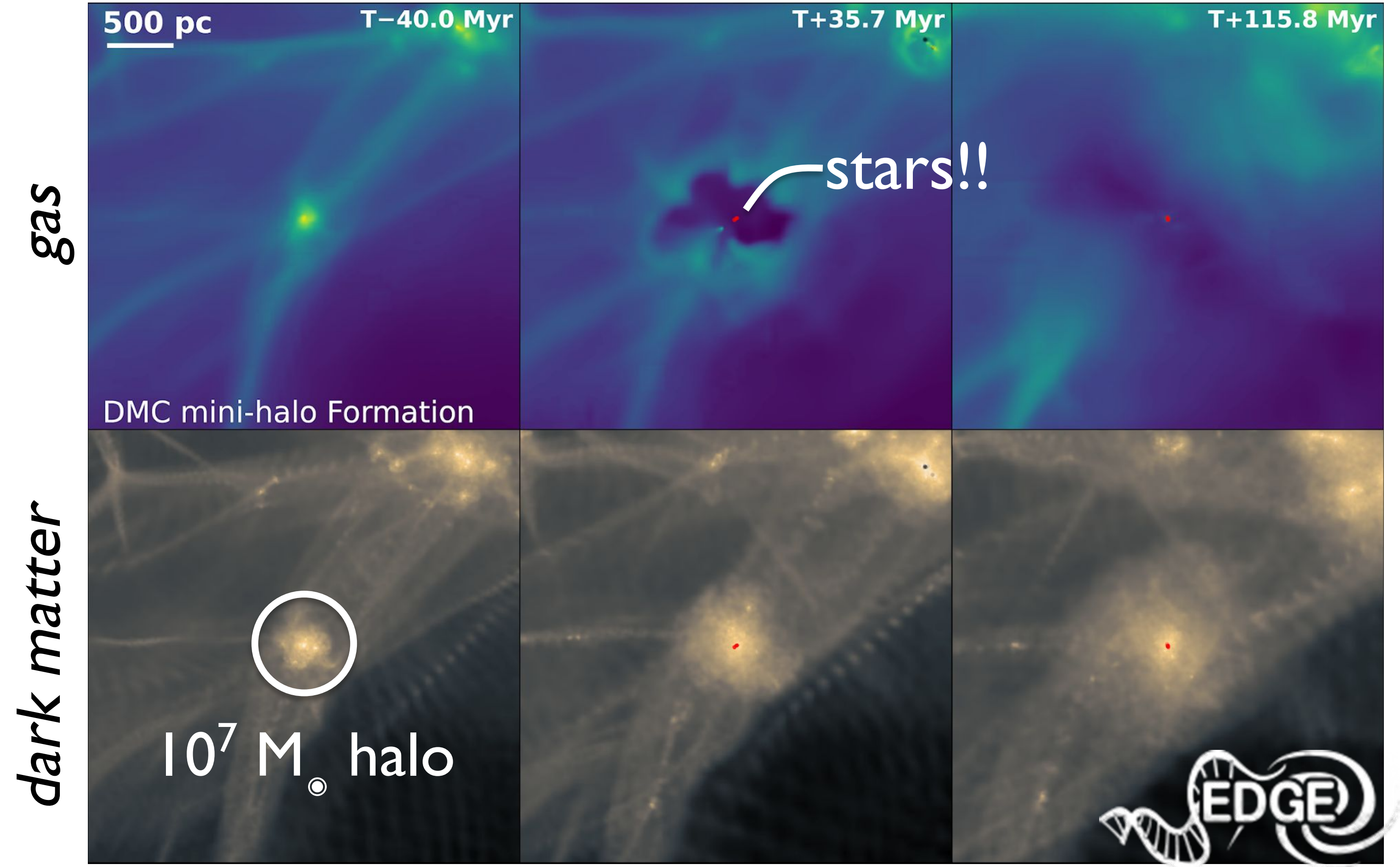

We find galaxies form in 10^7 $M_\odot$ dark matter halos!

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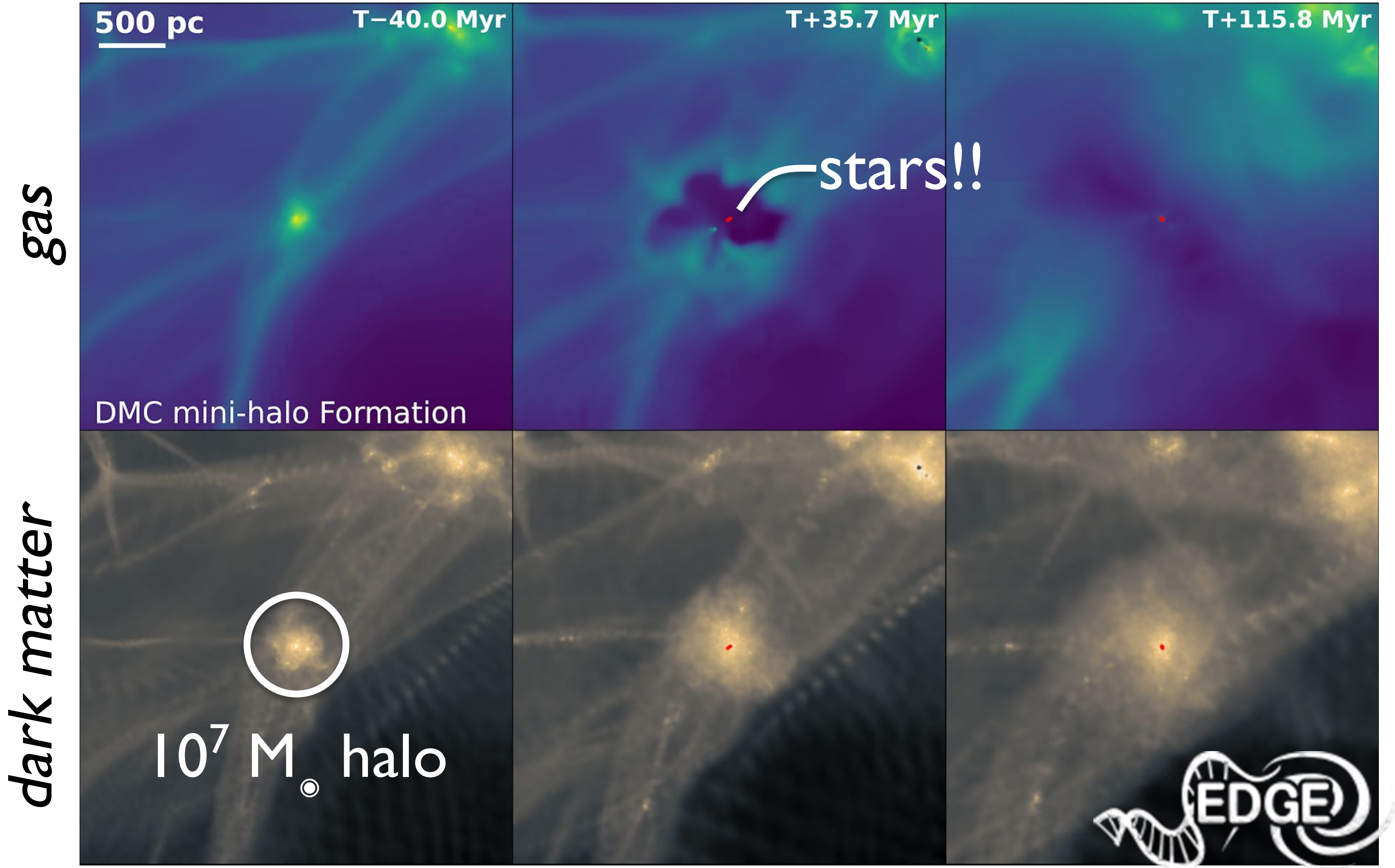

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Looks in-between **globular clusters** and dwarf galaxies!

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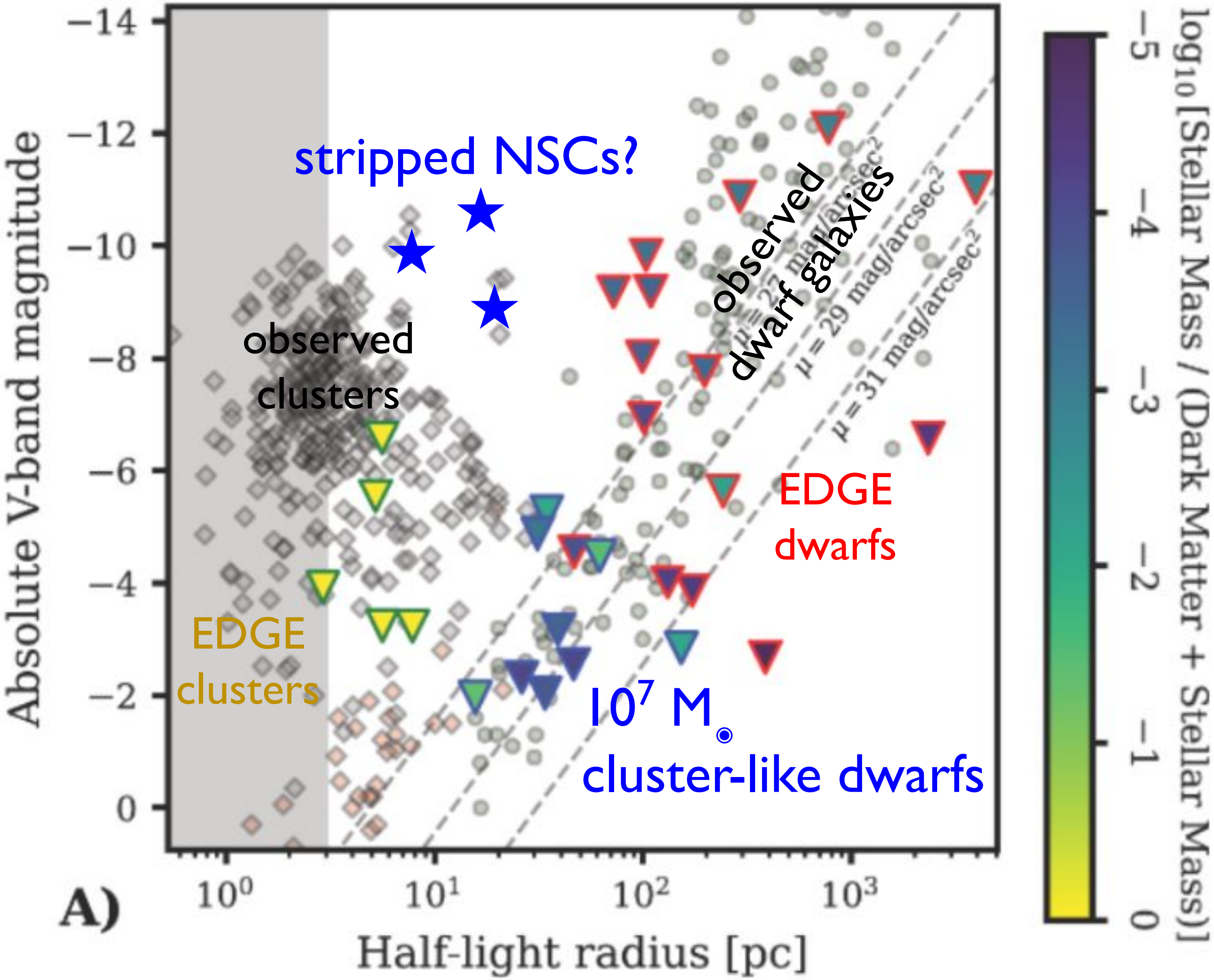
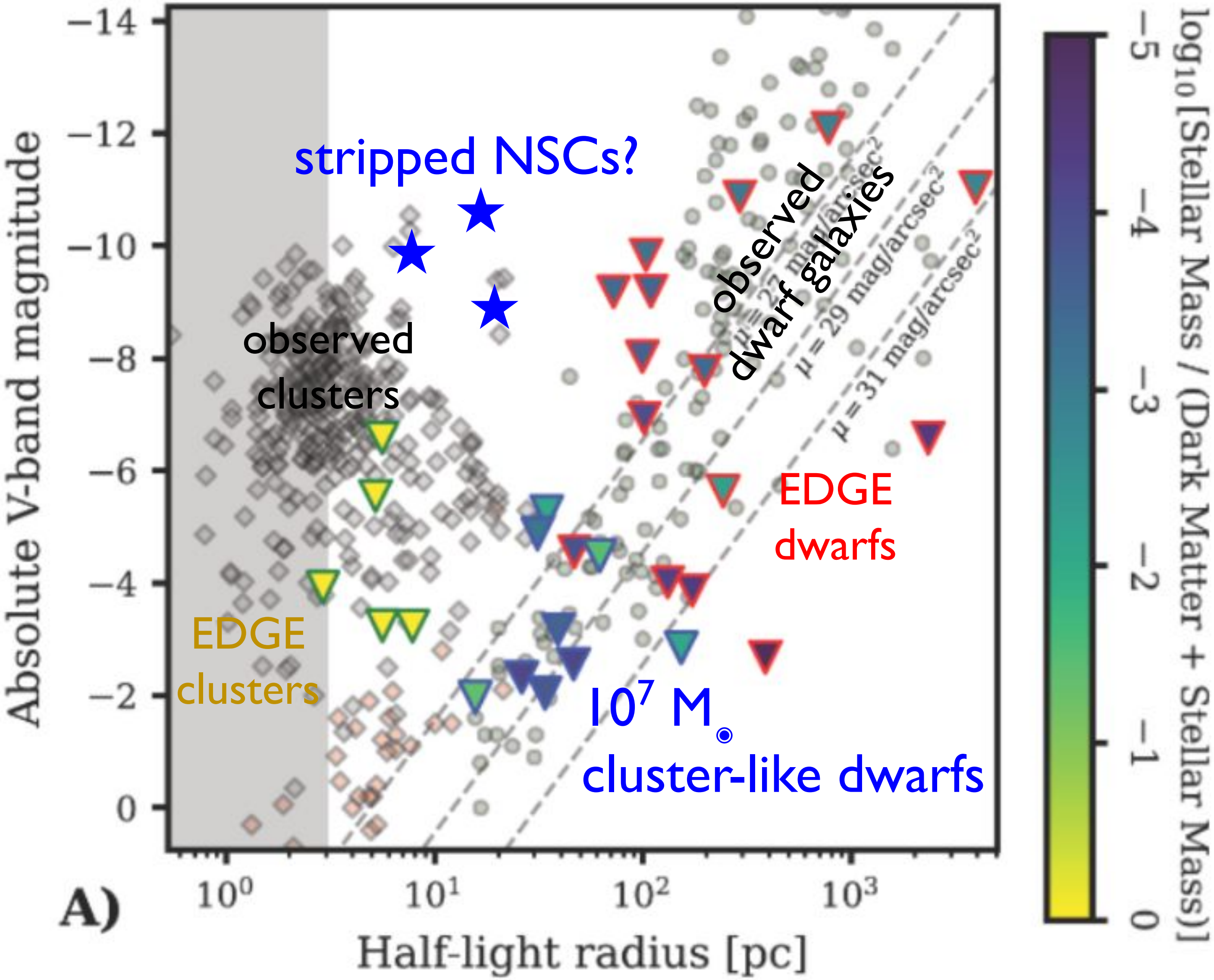
implications for SIDM | the faintest dwarfs



EDGE Collaboration

implications for SIDM | the faintest dwarfs


Izzy Gray *Ethan Taylor*



Globular cluster-like dwarfs form in halos with v_{max} ~ 7-9 km/s at birth (z~6-10).

EDGE Collaboration

implications for SIDM | the faintest dwarfs

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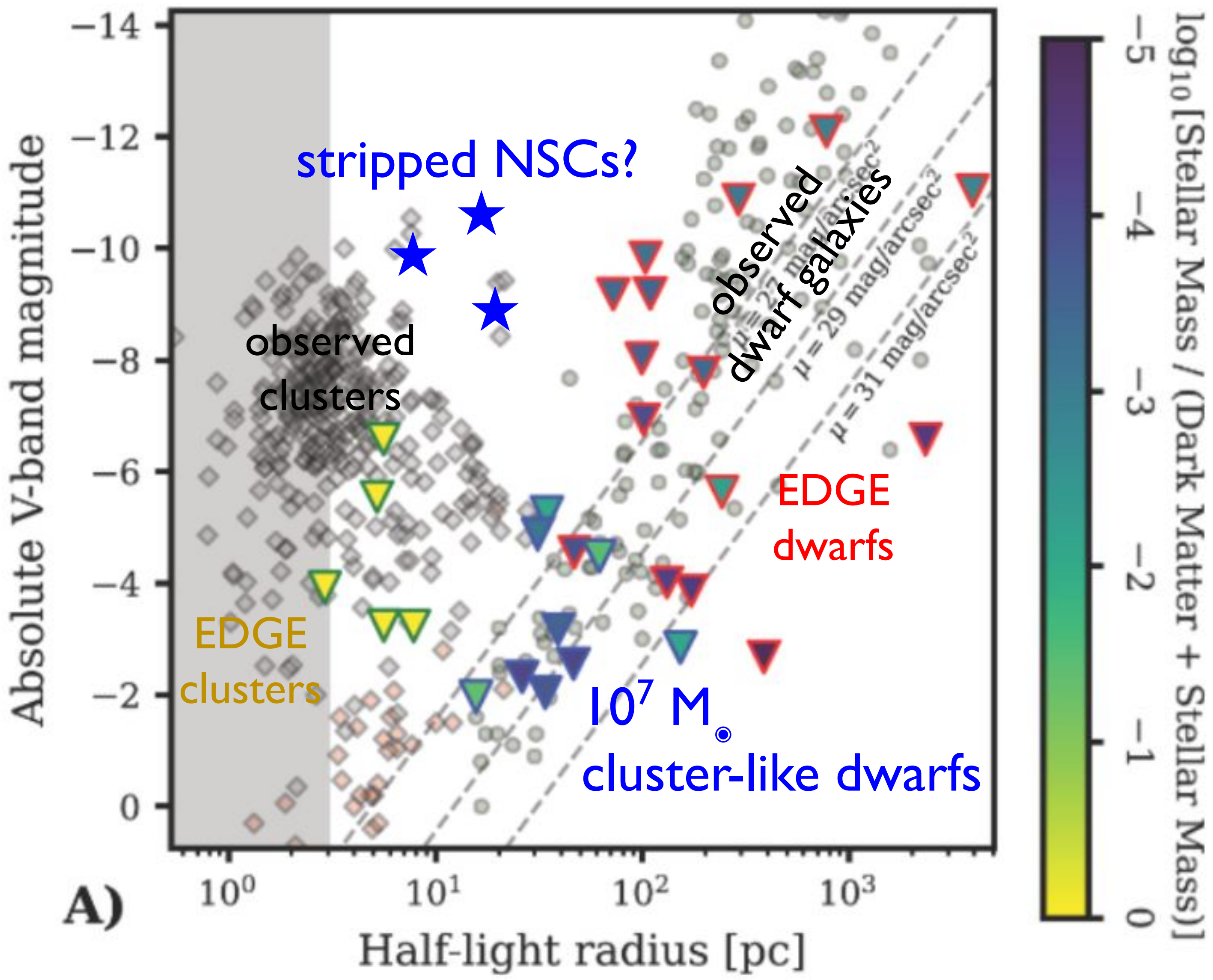

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Change in vmax due to SIDM at high redshifts could affect dwarf galaxy abundances?

EDGE Collaboration

insights on SIDM from the EDGE dwarfs

A dwarf galaxy's dark matter density evolution and growth history can significantly affect its observational properties.

Relation between SFR and vmax indicates that core expansion and core collapse may affect SFHs and thus M_* in dwarfs.

Increase in vmax in deep core collapse could cause an increase in star formation then quenching (and potentially a nuclear star cluster).

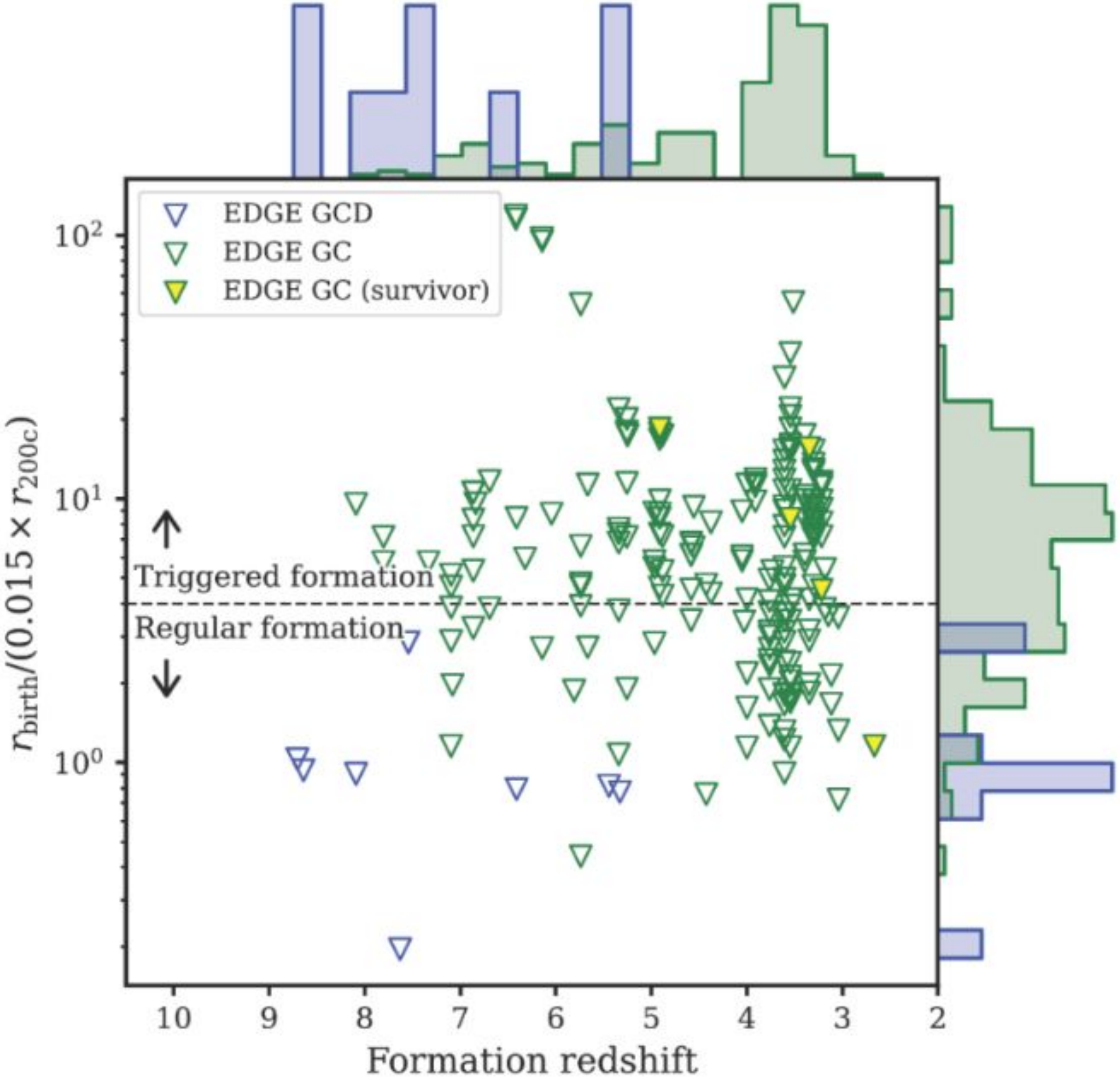
Globular cluster-like dwarf galaxies can form in $10^7\ M_\odot$ halos.
Changes in vmax due to SIDM at high redshifts could affect dwarf abundances.

EXTRAS

resolving the faintest galaxies

with super high resolution sims

Ethan Taylor



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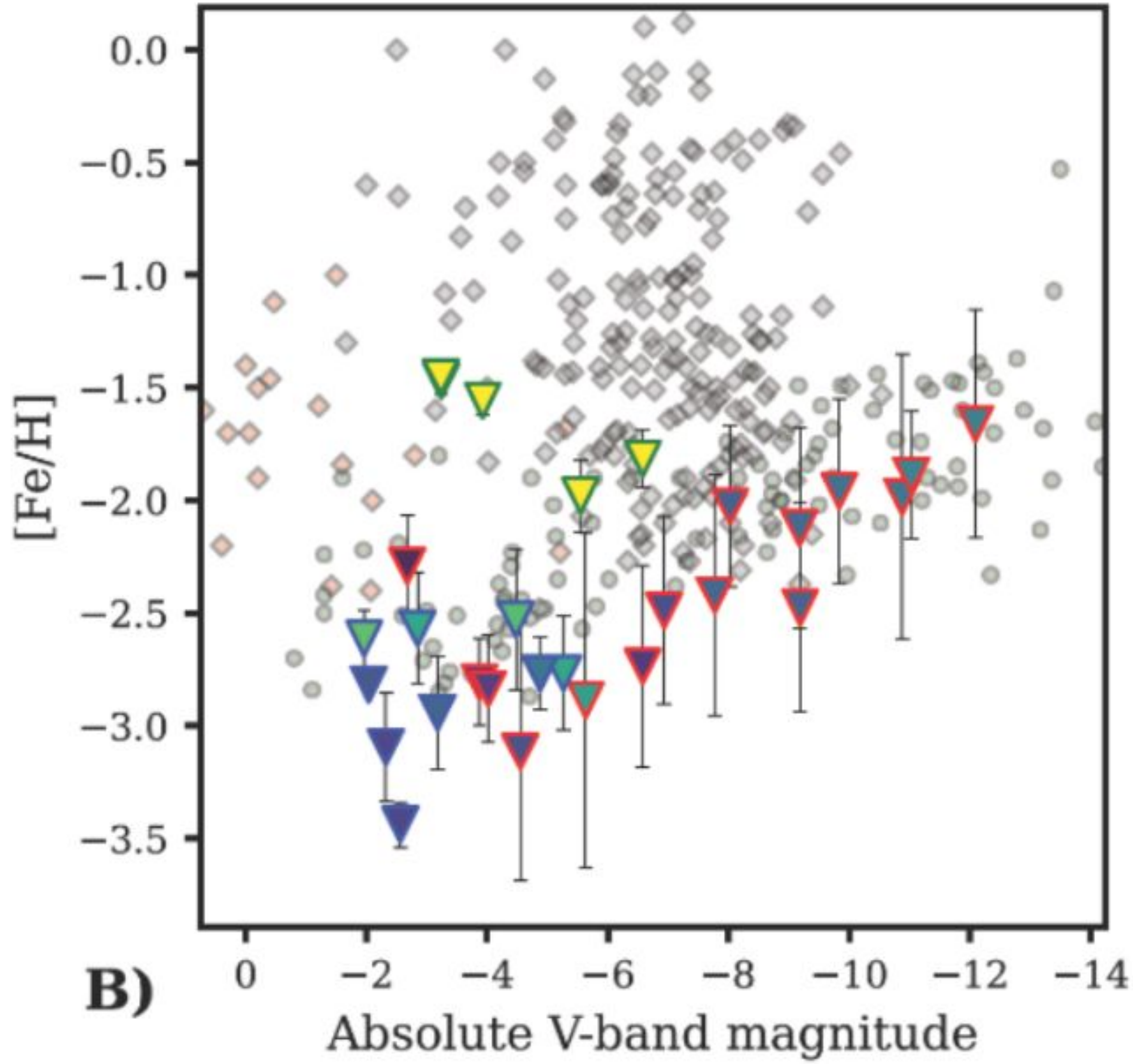

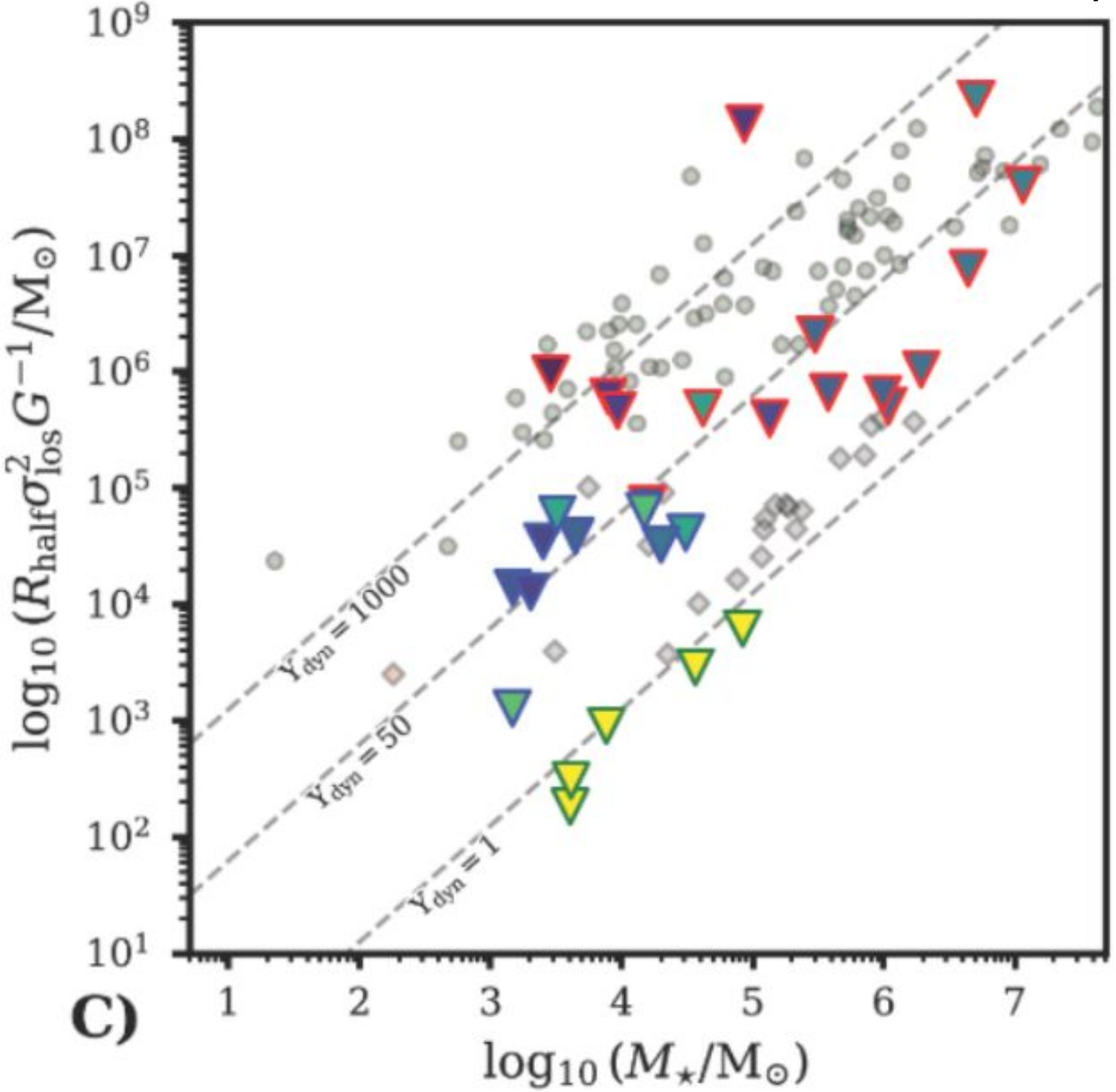

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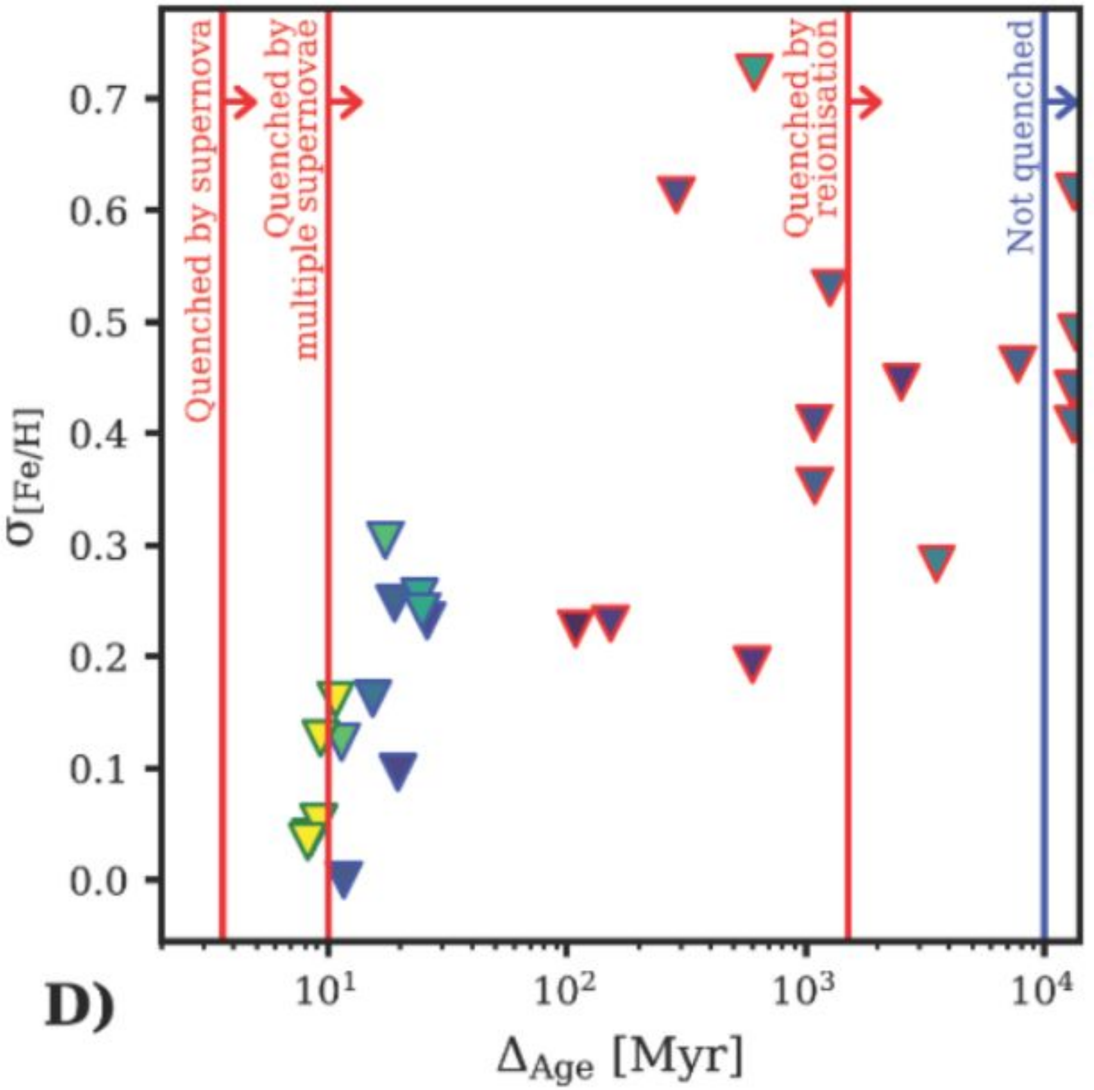
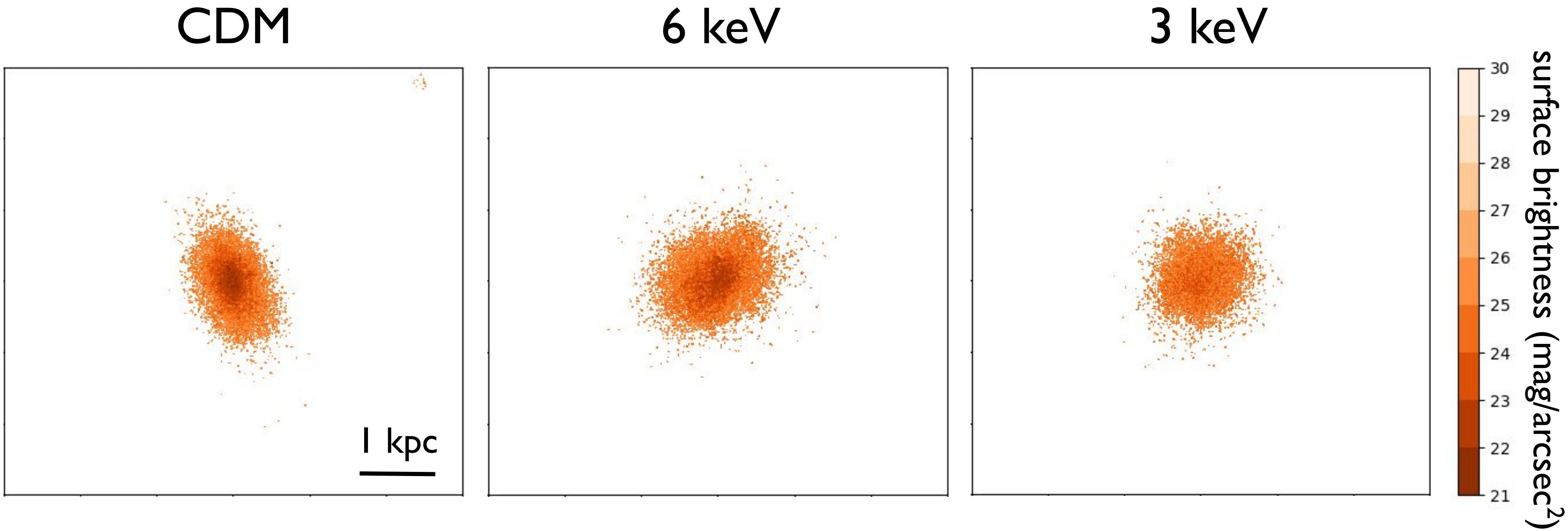


towards dark matter constraints | WDM

Dwarf galaxies fewer, fainter… *and puffier?*



Accreted subhalos disrupt when their densities ~ host halo's densities.

WDM halos have lower densities → disrupts at larger radii → puffier?

SYK, Read+, in prep

towards dark matter constraints | WDM

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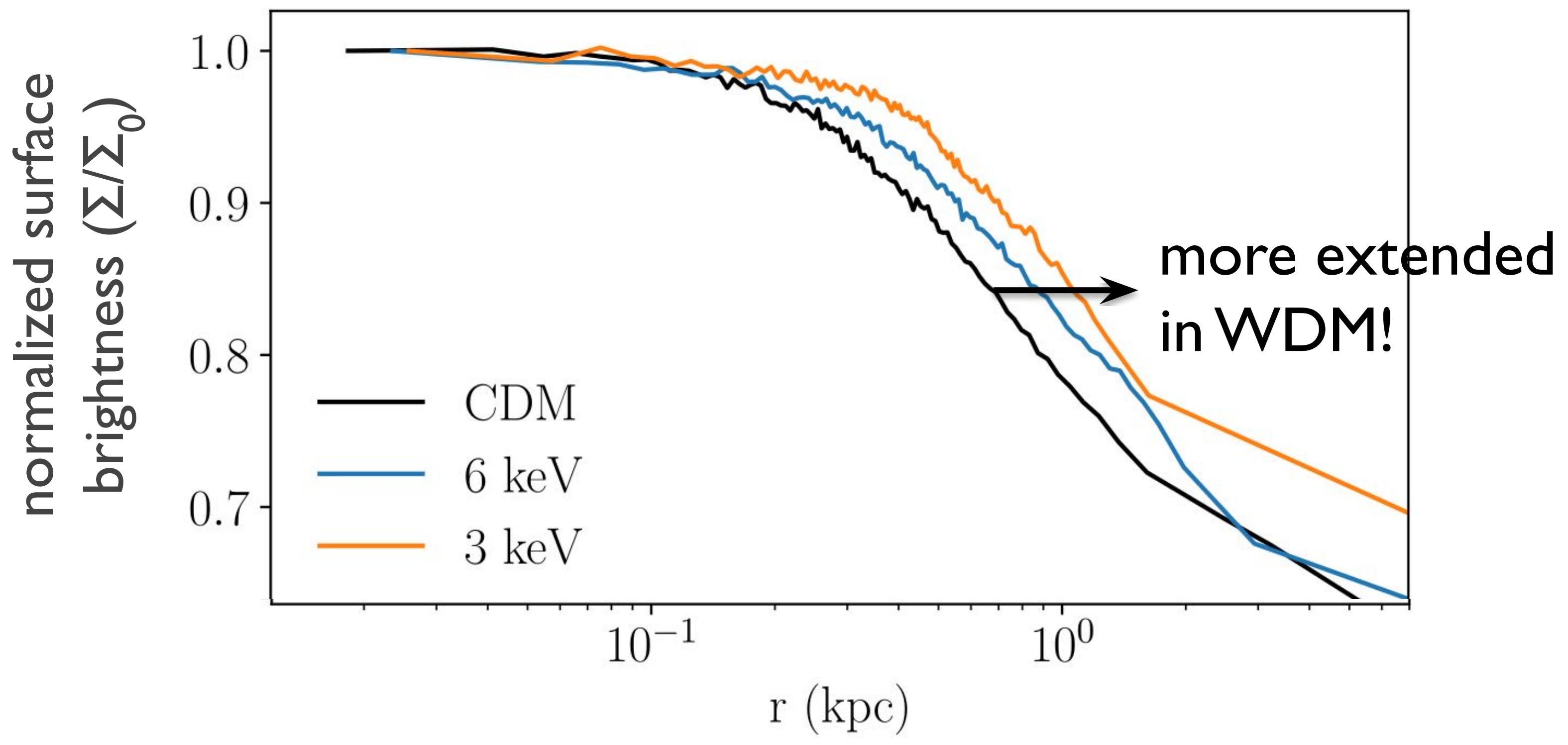
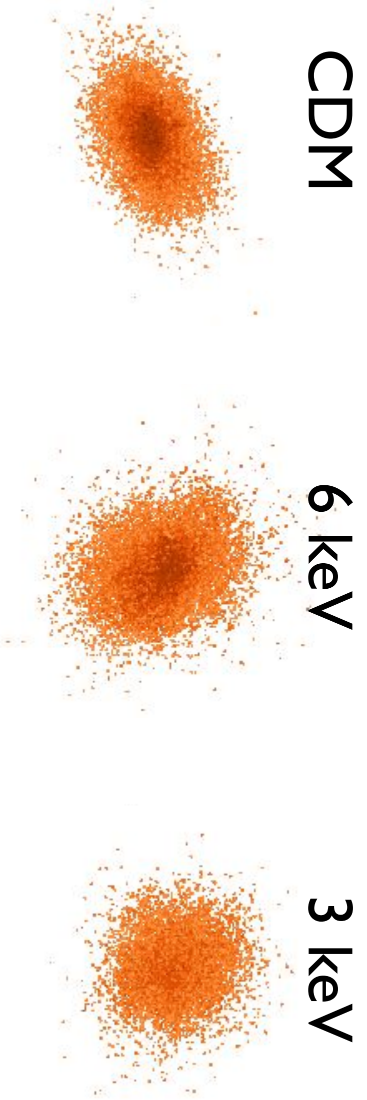




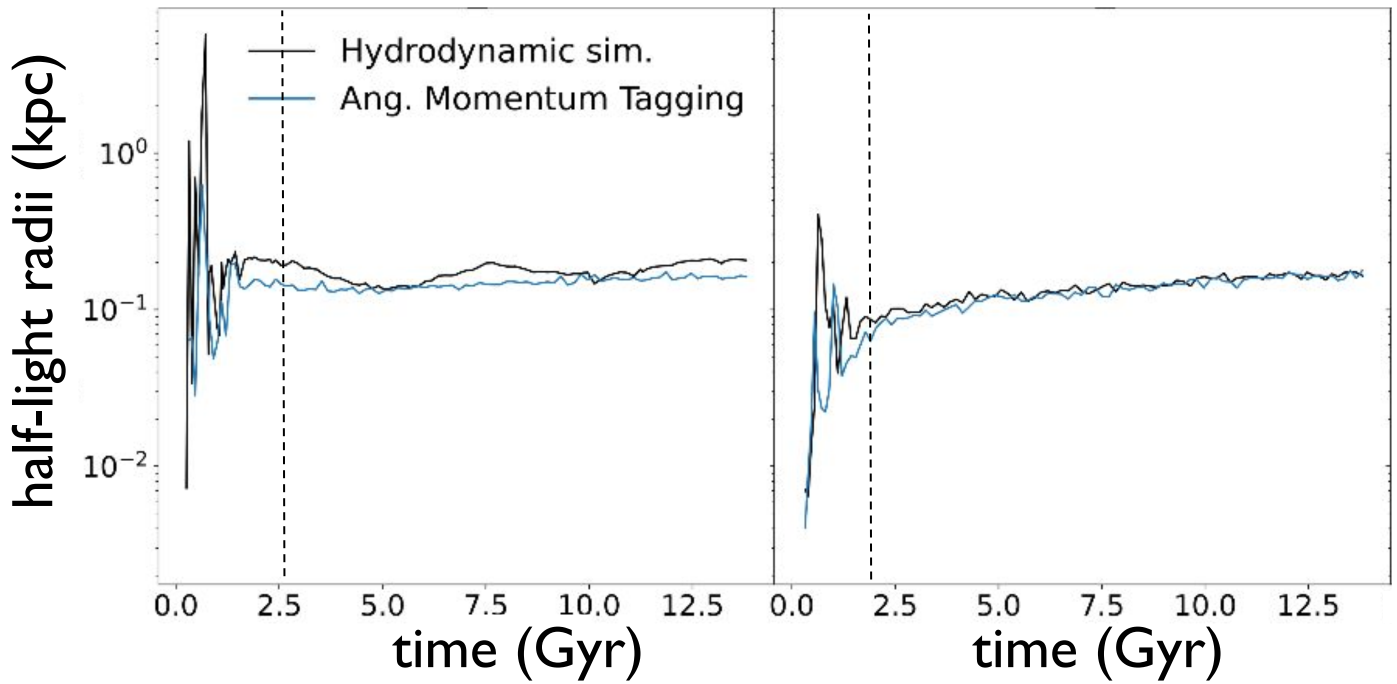
Triple whammy! WDM constraints based on number of dwarfs detected could be overestimated?

SYK, Read+, in prep

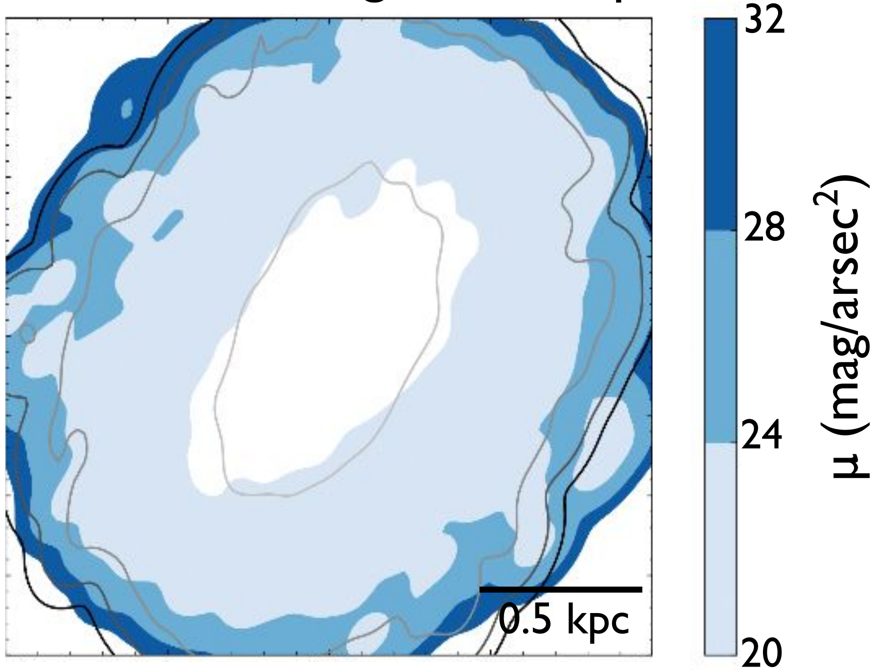
modeling other dwarf populations | DarkLight

Sushanta Nigudkar

New model for sizes of dwarf galaxies—truncated by reionization!



2D surface brightness map



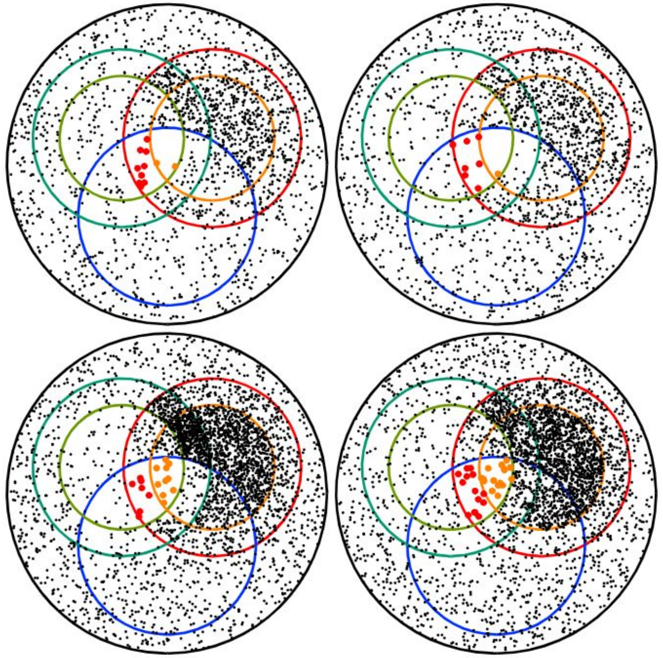
New particle tagging tool based on angular momentum can generate mock dwarf galaxies in dark matter only simulations.

Nigudkar, SYK, Pontzen+, in prep

modeling other dwarf populations | DarkLight

Susan Hutton

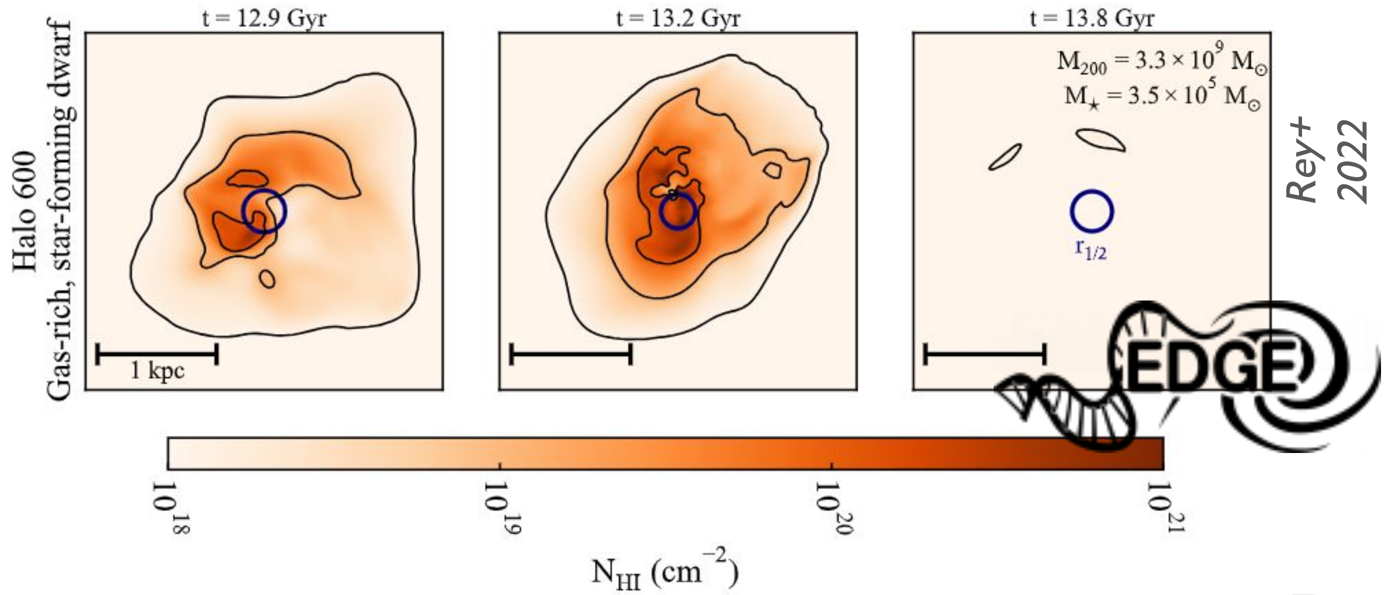
Where are all the gas-rich dwarfs?



Tollerud & Peek 2018

~10 should be detectable in the Local Group, but we see none!

EDGE finds significant variability in star-forming dwarfs!



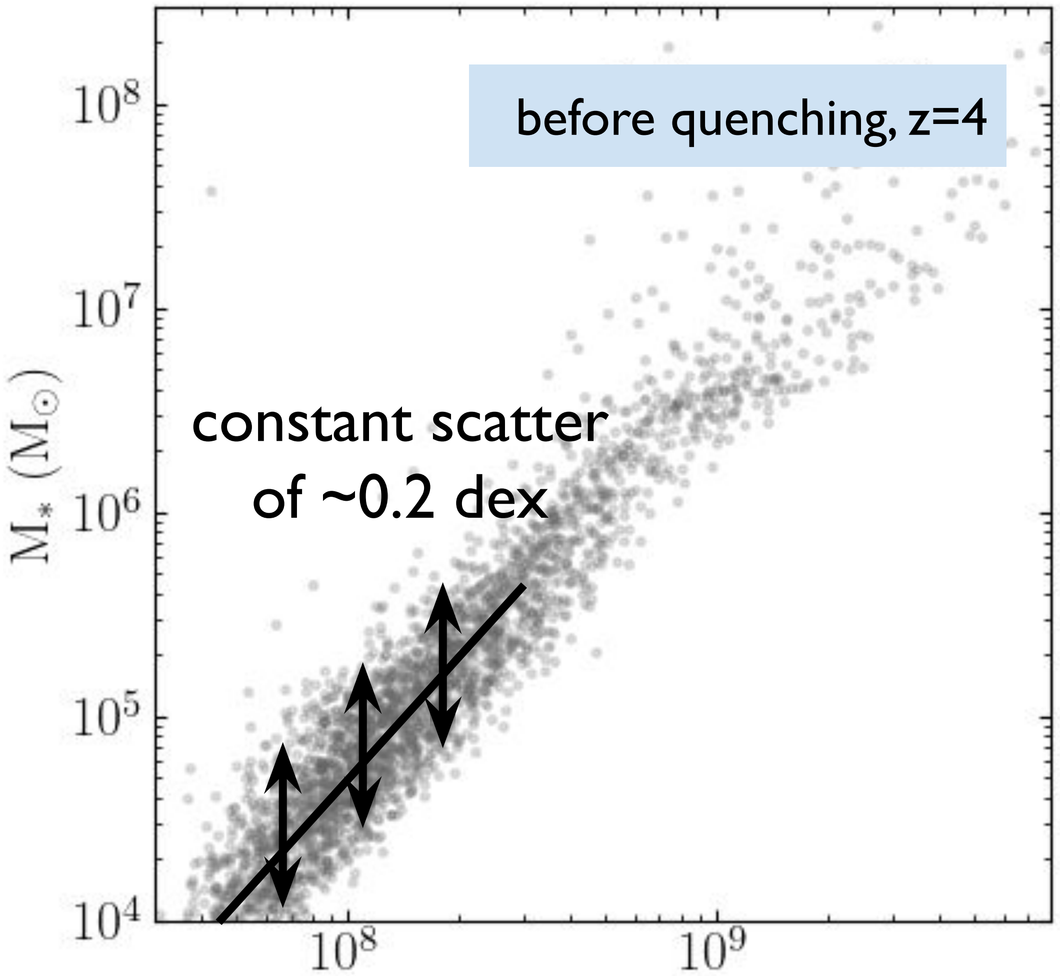
Rey+ 2022

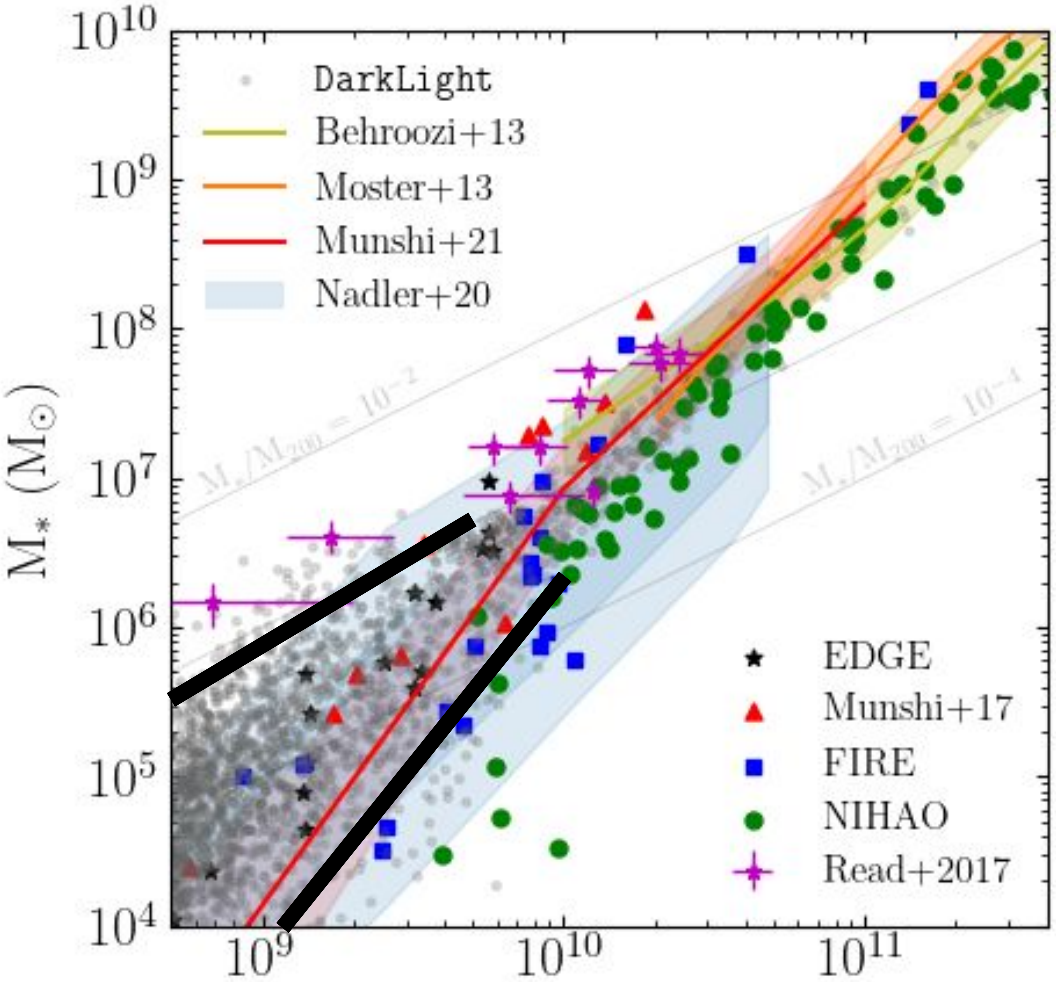
Building gas variability model into DarkLight.

Sue is a Daphne Jackson Postdoctoral Fellow (given to those with career breaks)!

Hutton, SYK+, in prep

the impact of reionization quenching

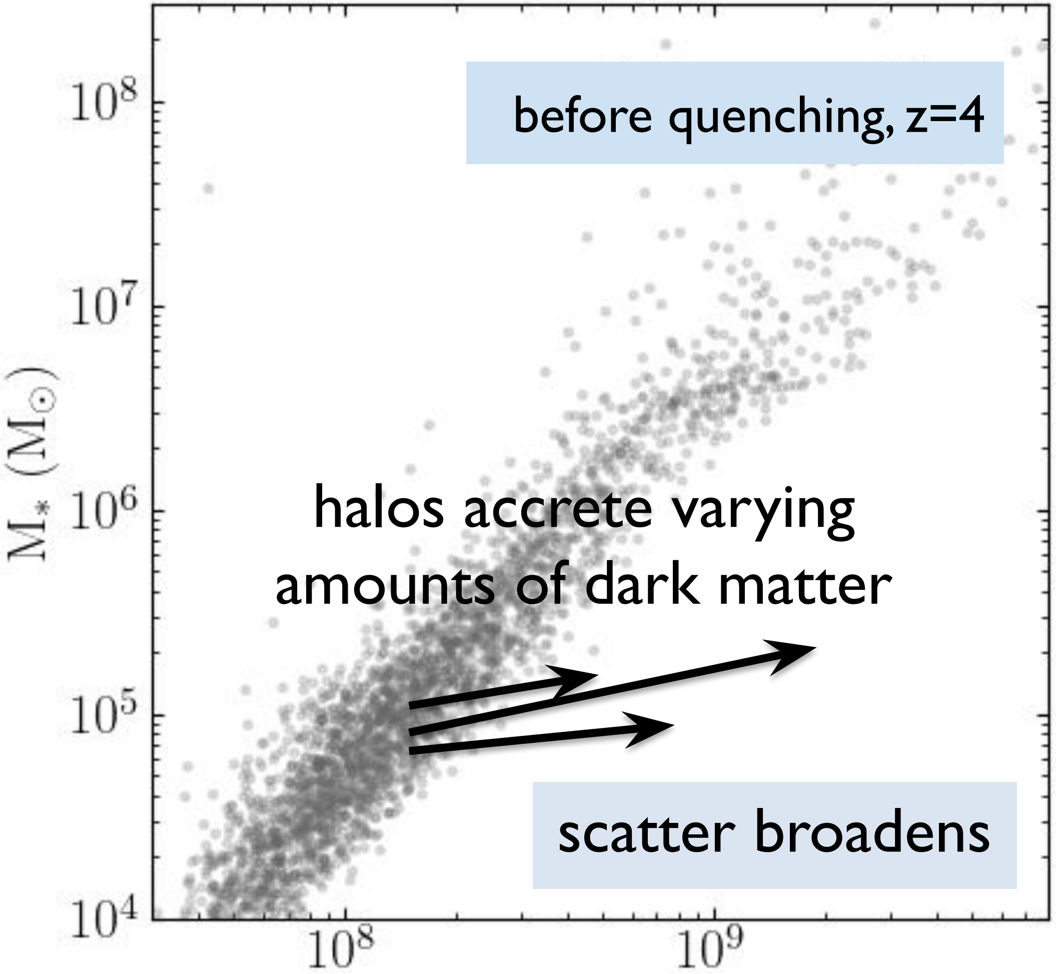


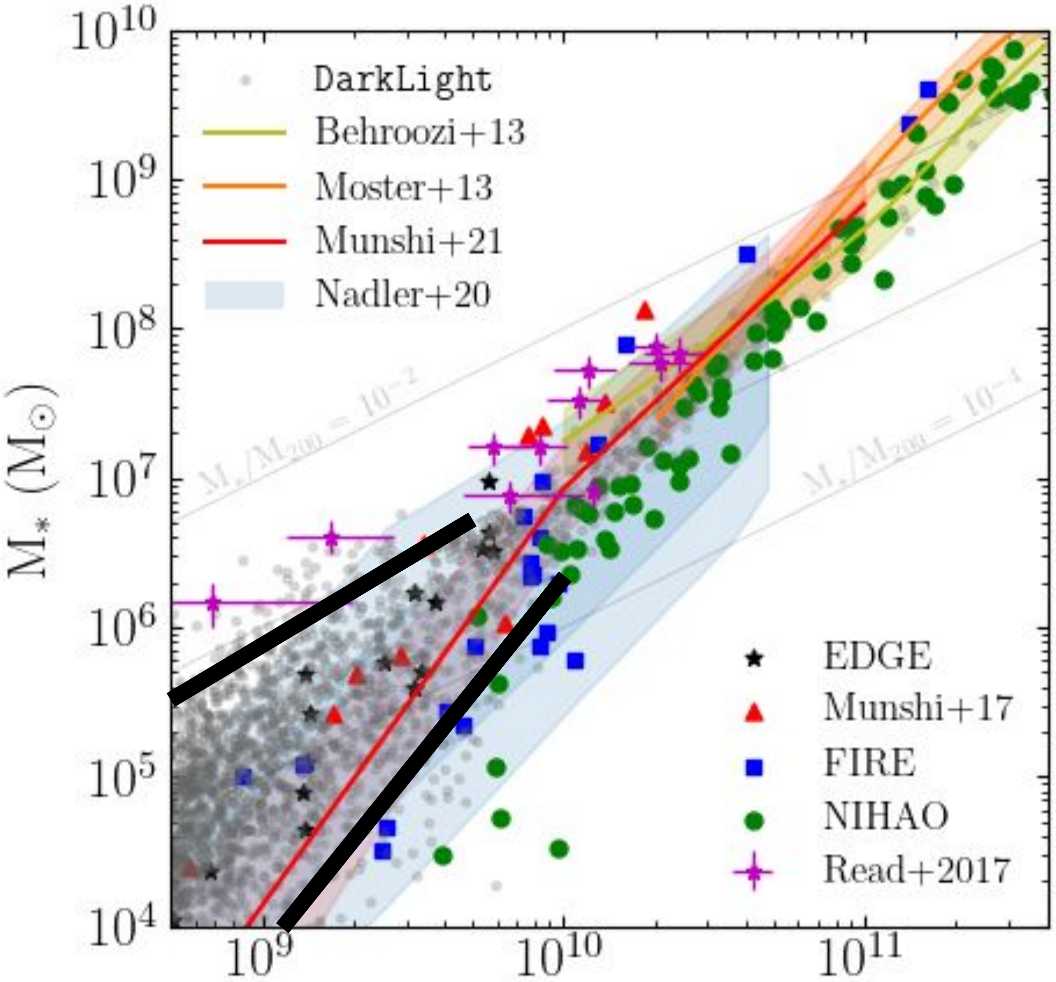


Initially had constant scatter, only grows following reionization!

SYK+ 2024 (arXiv:2408.15214)

the impact of reionization quenching





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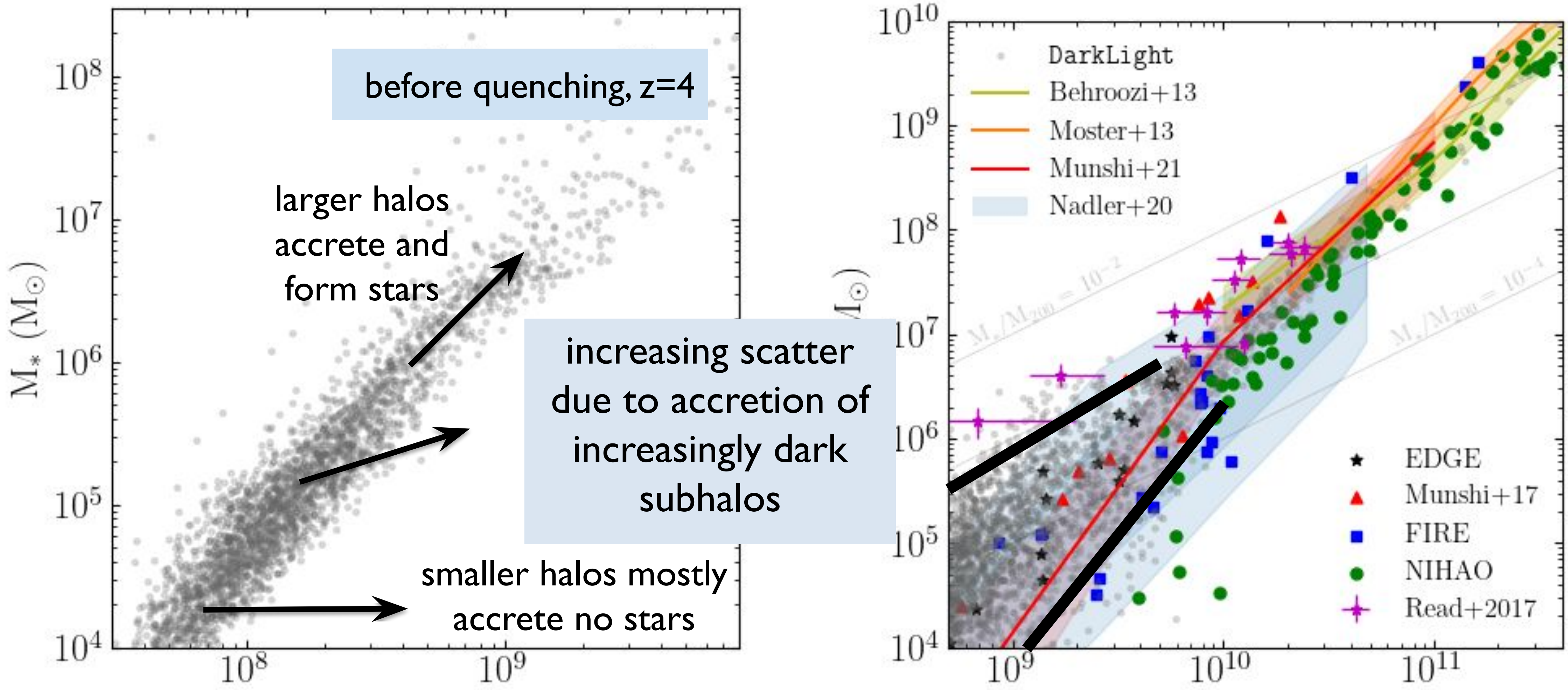

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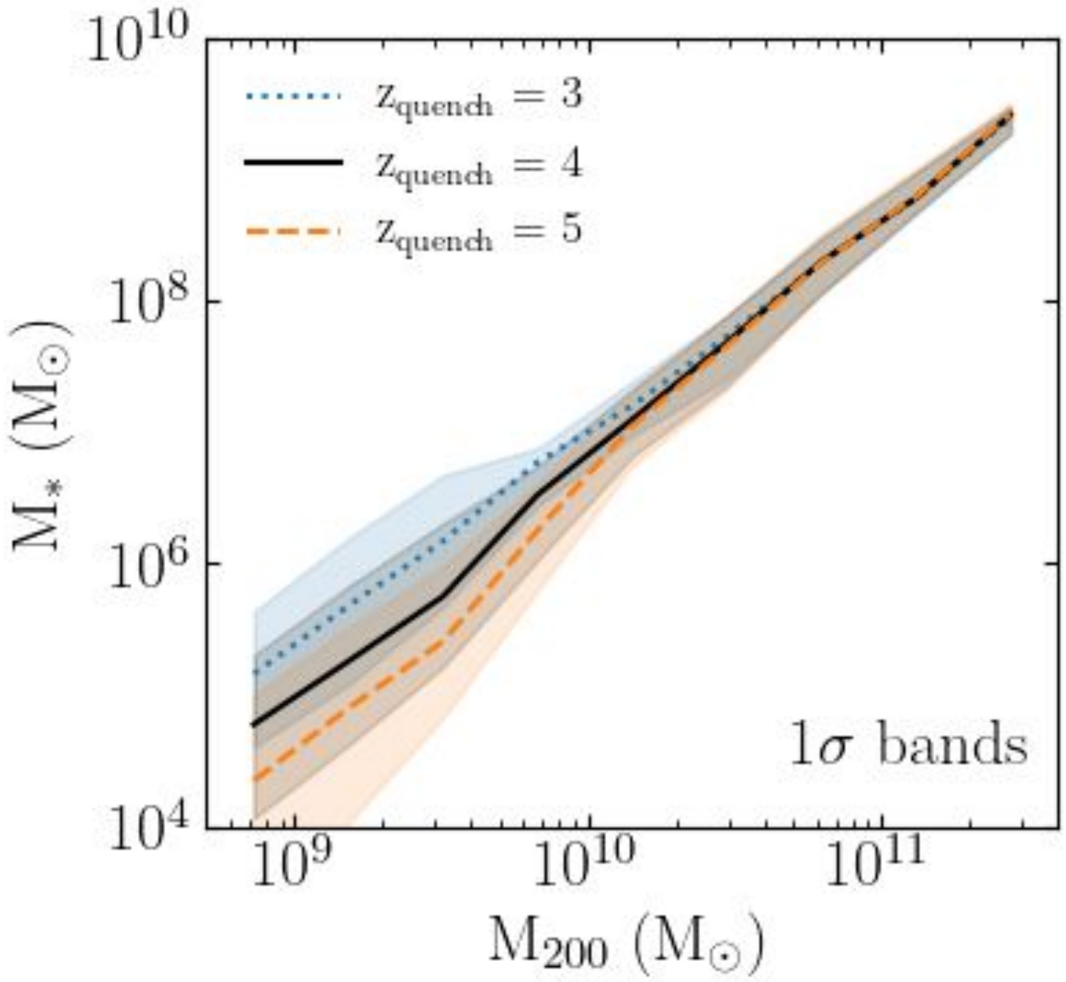
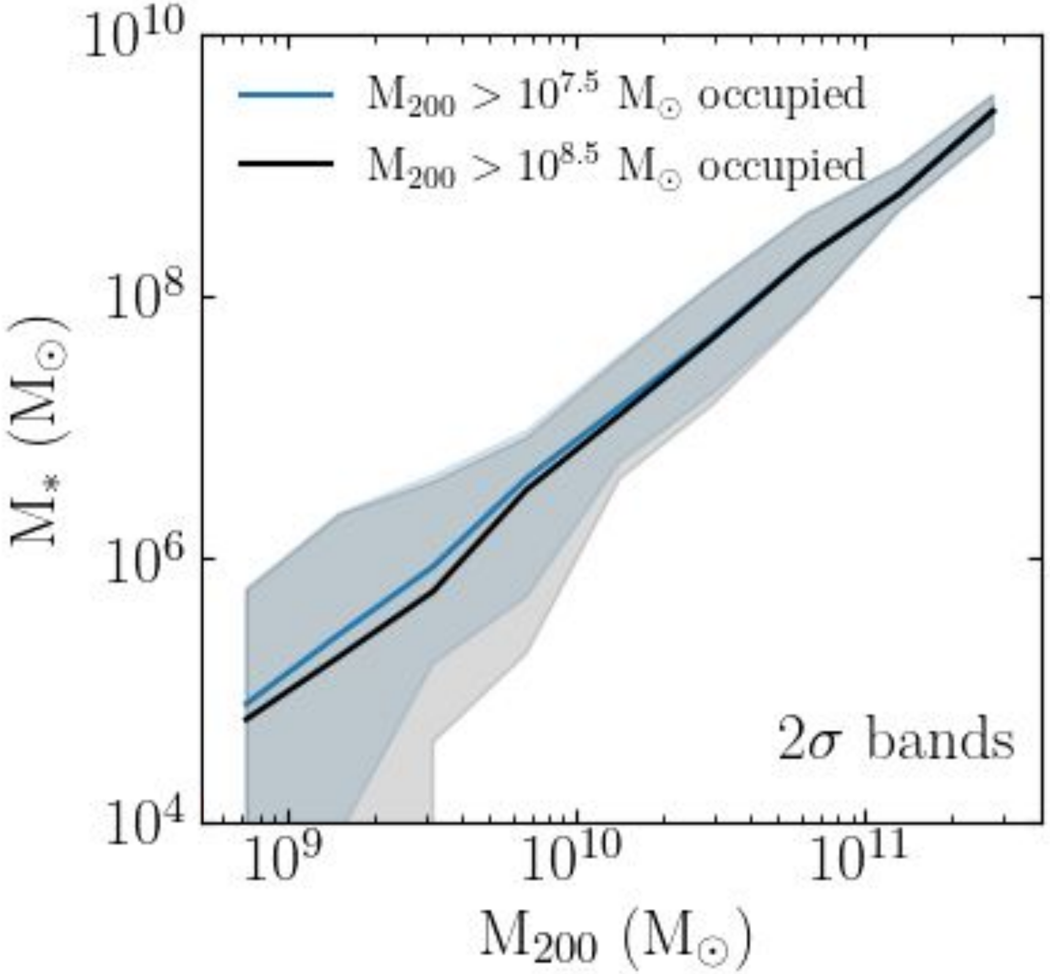


early z_q = 5	fiducial z_q = 4	late z_q = 3
stronger knee	slight knee	no knee
slope decreases below knee		slope increases below knee
+0.06 dex	0.55 dex 1σ scatter for 10^9 $M_\odot$ halos	-0.05 dex

Changing redshift of reionization quenching affects SMHM scatter, slope, and knee!

SYK+, in prep

the impact of reionization quenching



If $10^{7.5}\ M_\odot$ halos occupied:

1σ scatter decreases by 0.07 dex

for $10^9\ M_\odot$ halos

If more low-mass halos are occupied, SMHM will have smaller scatter.

SYK+, in prep