A recipe for Ultra Diffuse Galaxies

How to make UDGs with **FIRE**

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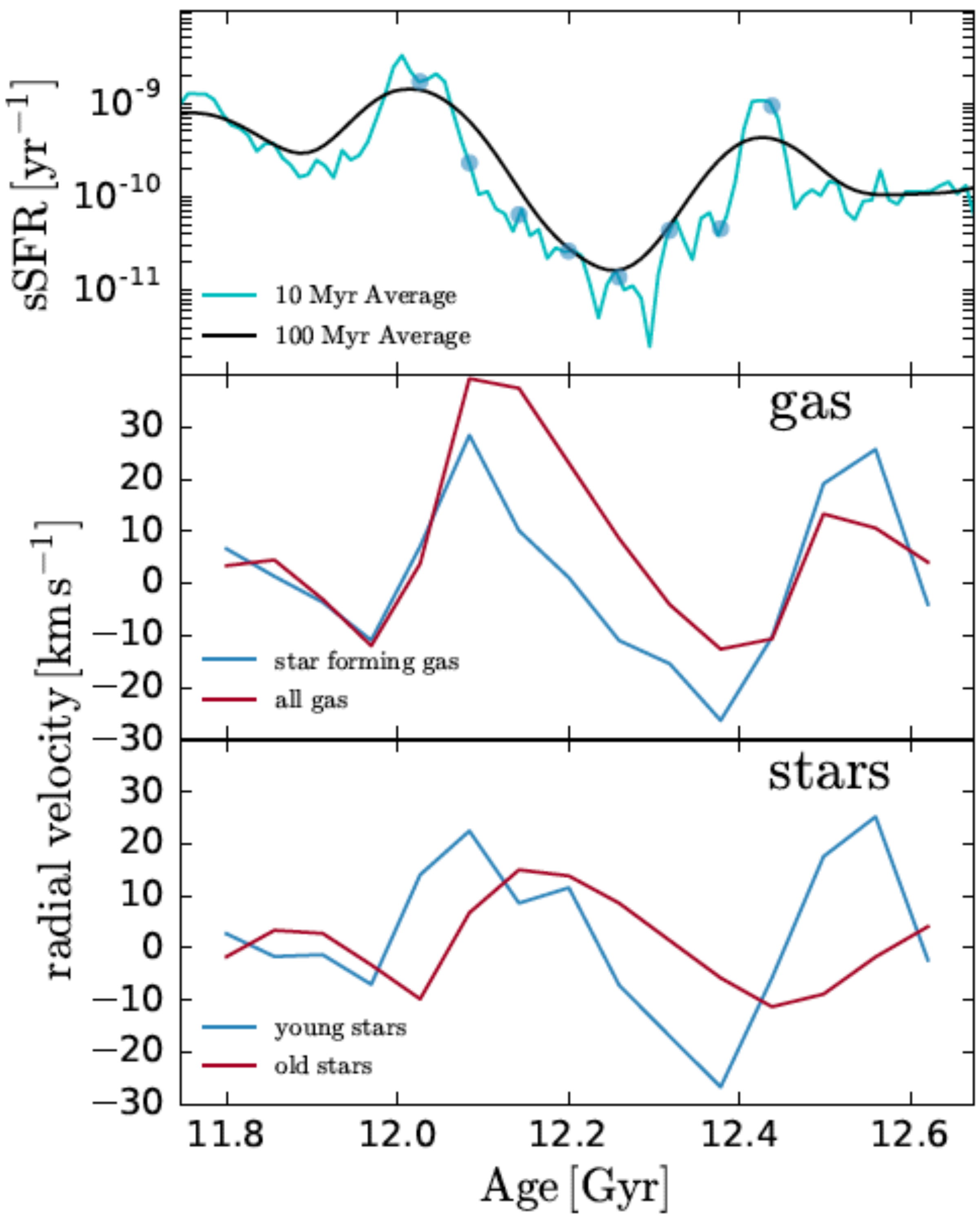
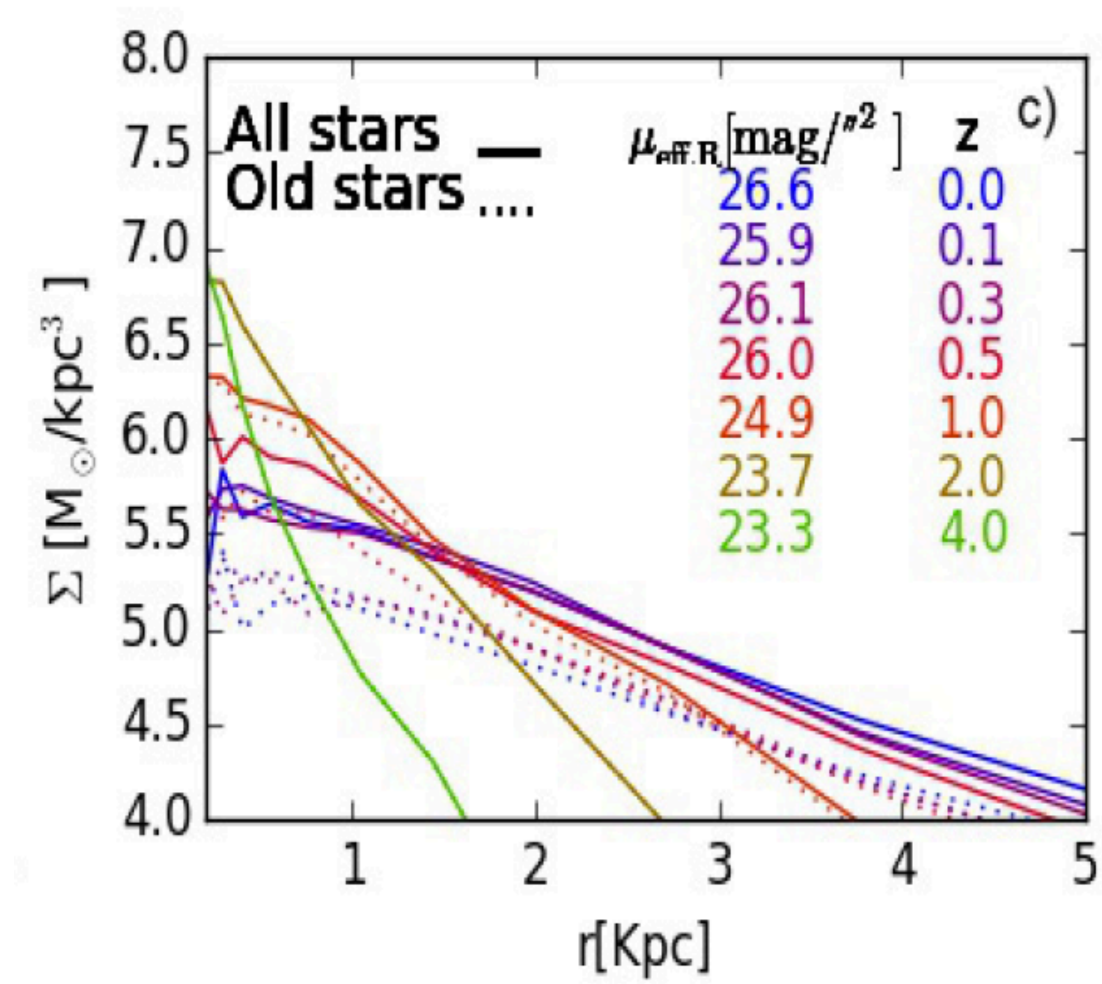
Lorentz centre workshop:
the bewildering nature of ultra diffuse galaxies

Galaxy expansion with feedback!

El-Badry+16



Di Cintio+17



Why galaxies are expanded by FB?

1. Stars formed with fast moving gas
2. Reduction of gravitational potential similar to dark matter halo expansion

Key aspects of UDGs

- Low surface brightness
- Huge size (effective radii)

Stellar feedback?

See also **Di Cintio+17**

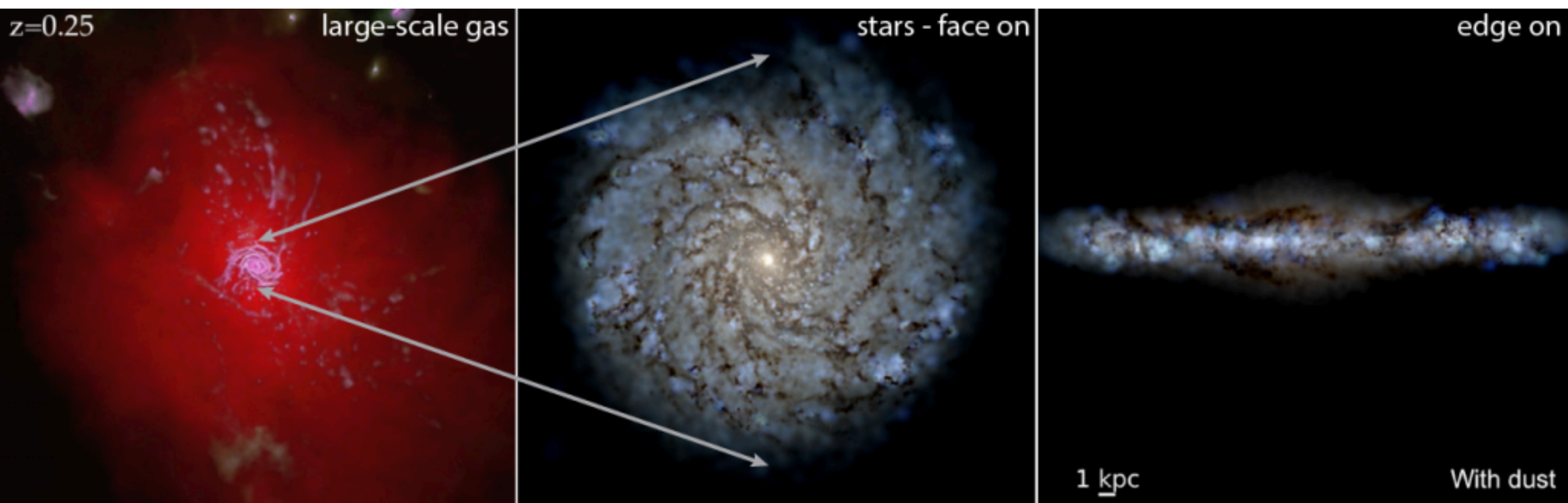
- *Red* in galaxy cluster; *Blue* in the group or field environments
- large inner DM mass
- a large number of globular clusters
- Radial distribution of cluster UDGs

Quenching?

FIRE 2 simulations

- High resolution cosmological zoom-in simulations
- Comprehensive stellar feedback: SNe, stellar winds, radiation pressure, photo ionisation etc
- reproduce Mstar-Mhalo, Mstar-metallicity, Mstar-SFR relations, kennicutt schmidt law, strong galactic winds in dwarf galaxies, etc.

https://fire.northwestern.edu/



The Recipe

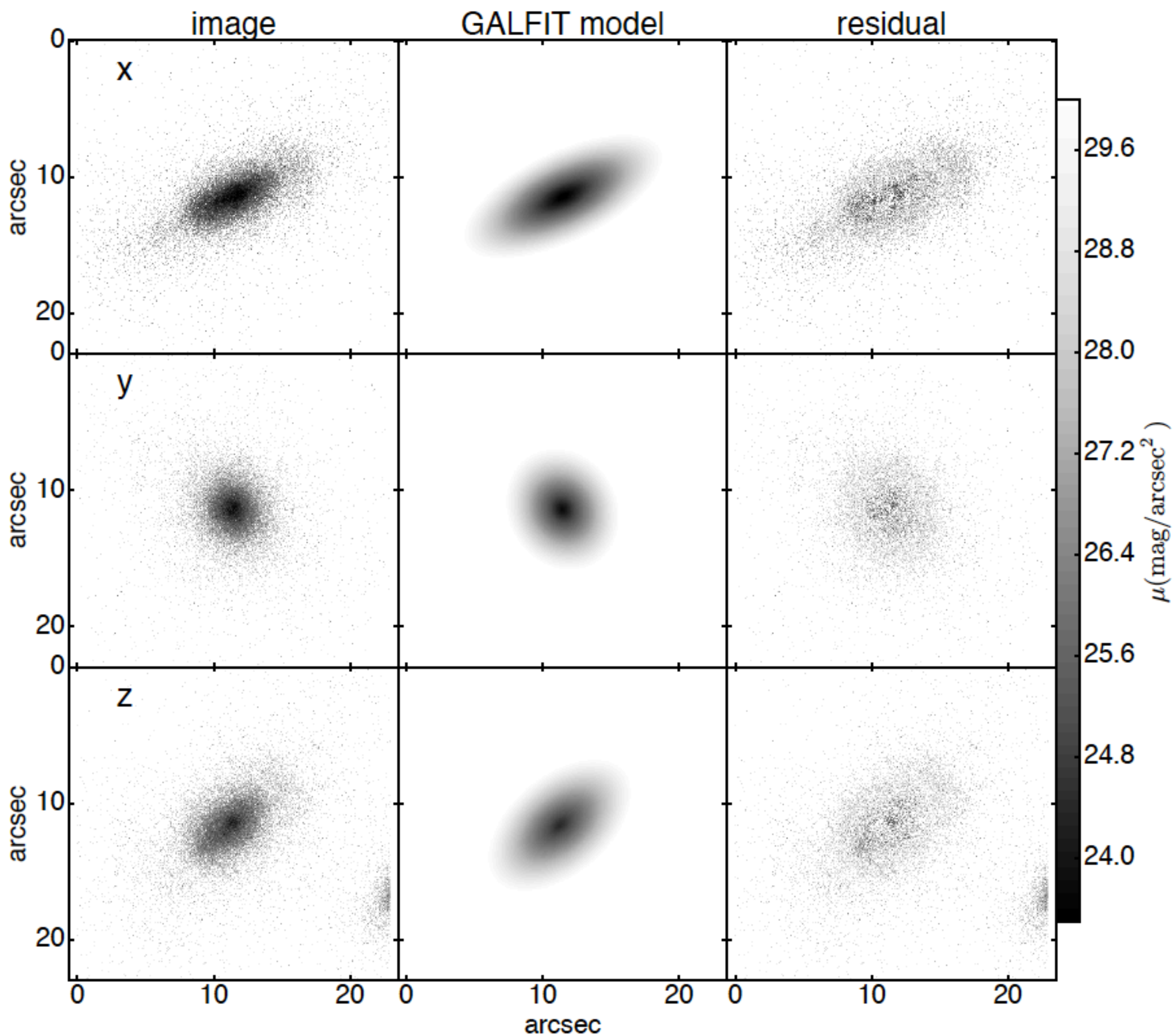
Ingredients:

- High resolution cosmological zoom-in simulations of isolated dwarf galaxies from the FIRE-2 simulations
- $M_{halo}(z=0) \sim 10^{10.5\text{-}11.5}$ M_{sun} (if evolve in the field)

Cooking directions:

- Taking the snapshot at quenching time t_q
- pro-process the galaxies to z=0 with
  - Stellar Population Synthesis model (FSPS)
- Mock observations with GALFIT

Passive evolution from z=1 with FSPS; no dust attenuation.



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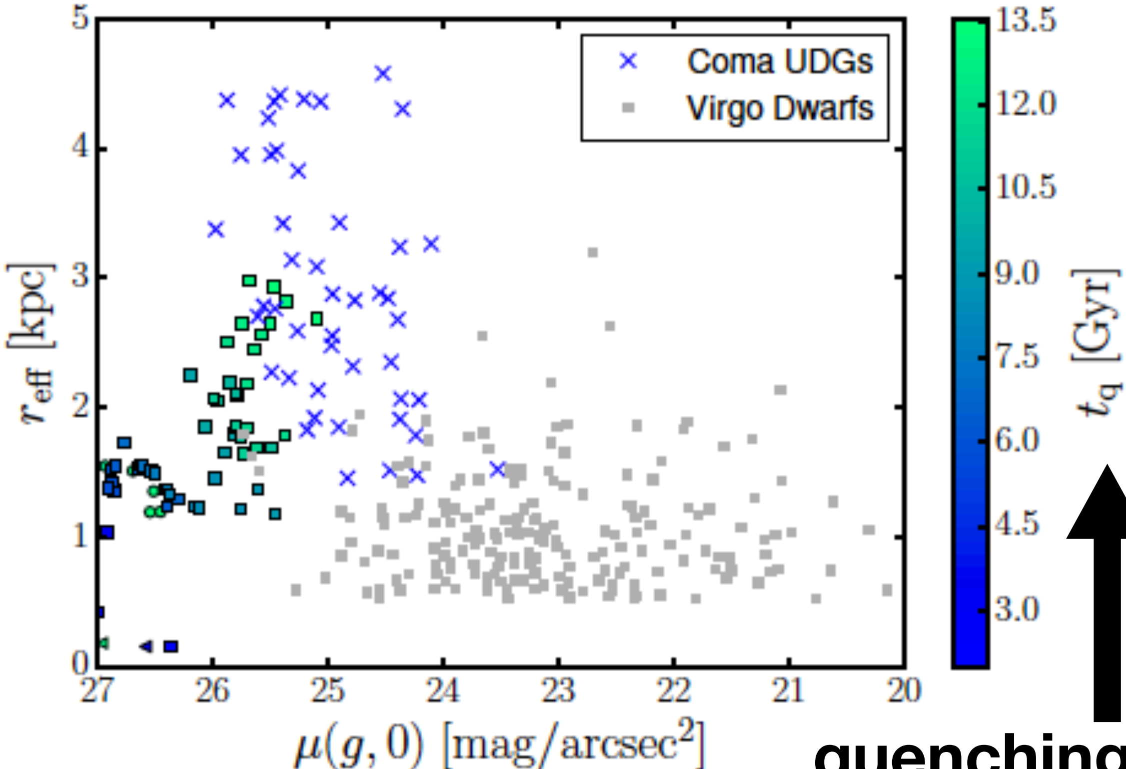
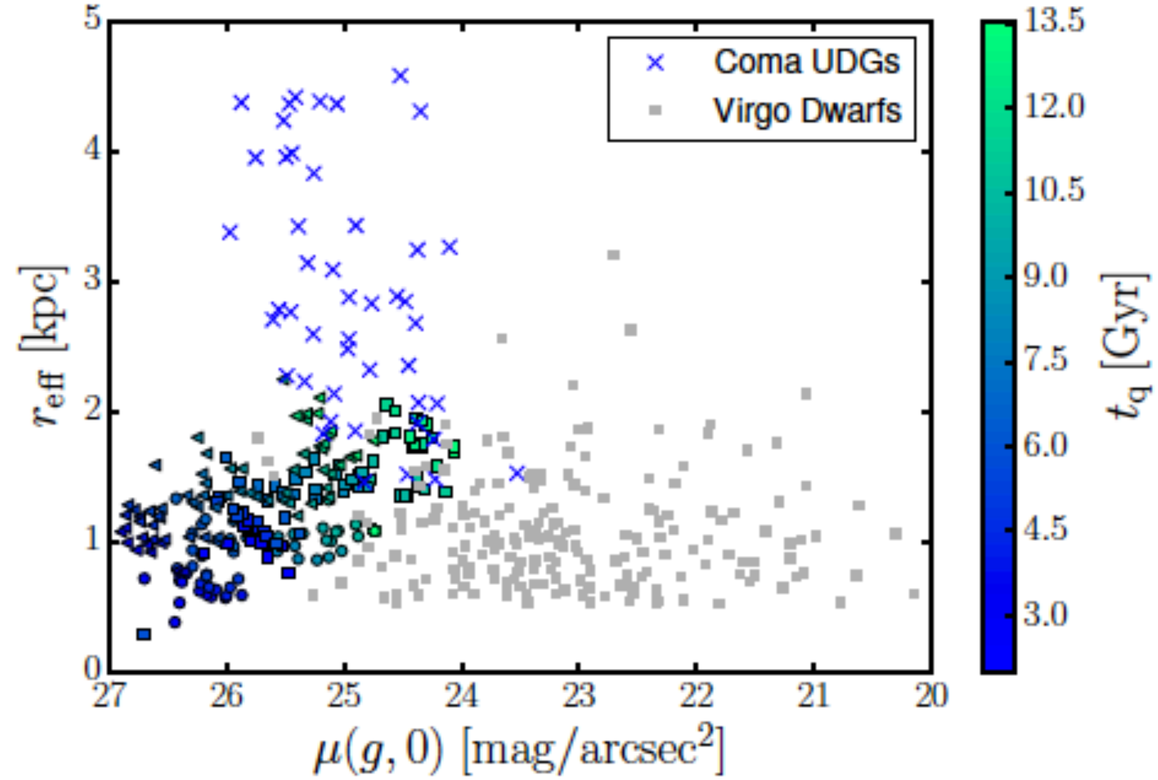
UDGs: quenching time vs Mstar

M_{star} ~5e7 m10z

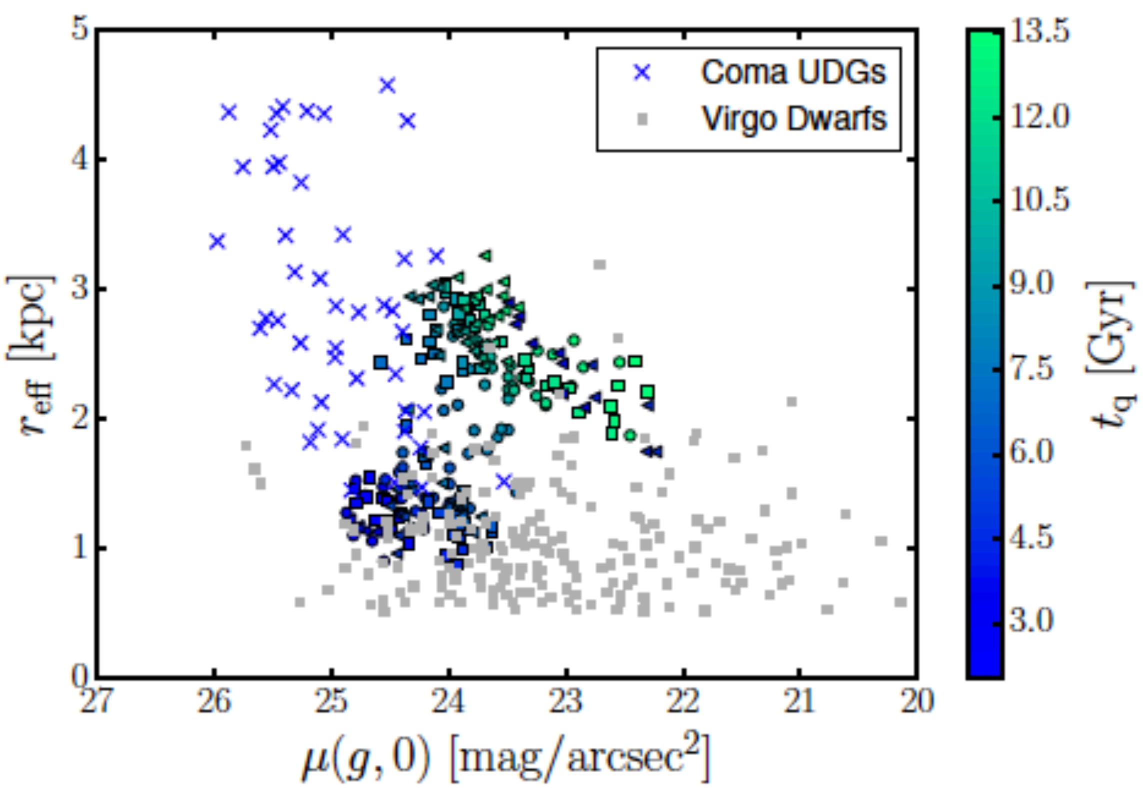


M_{star} ~1e8 m11a

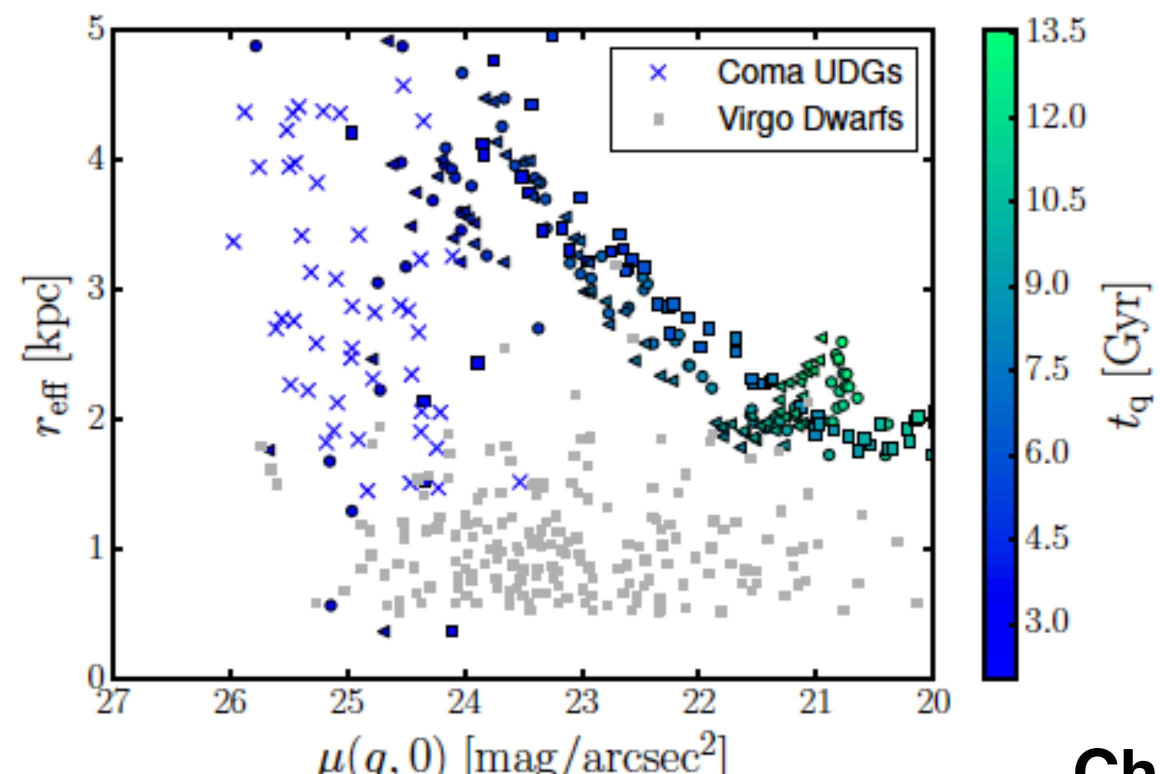


quenching time

M_{star} ~5e8 m11c



M_{star} ~1e9 m11f



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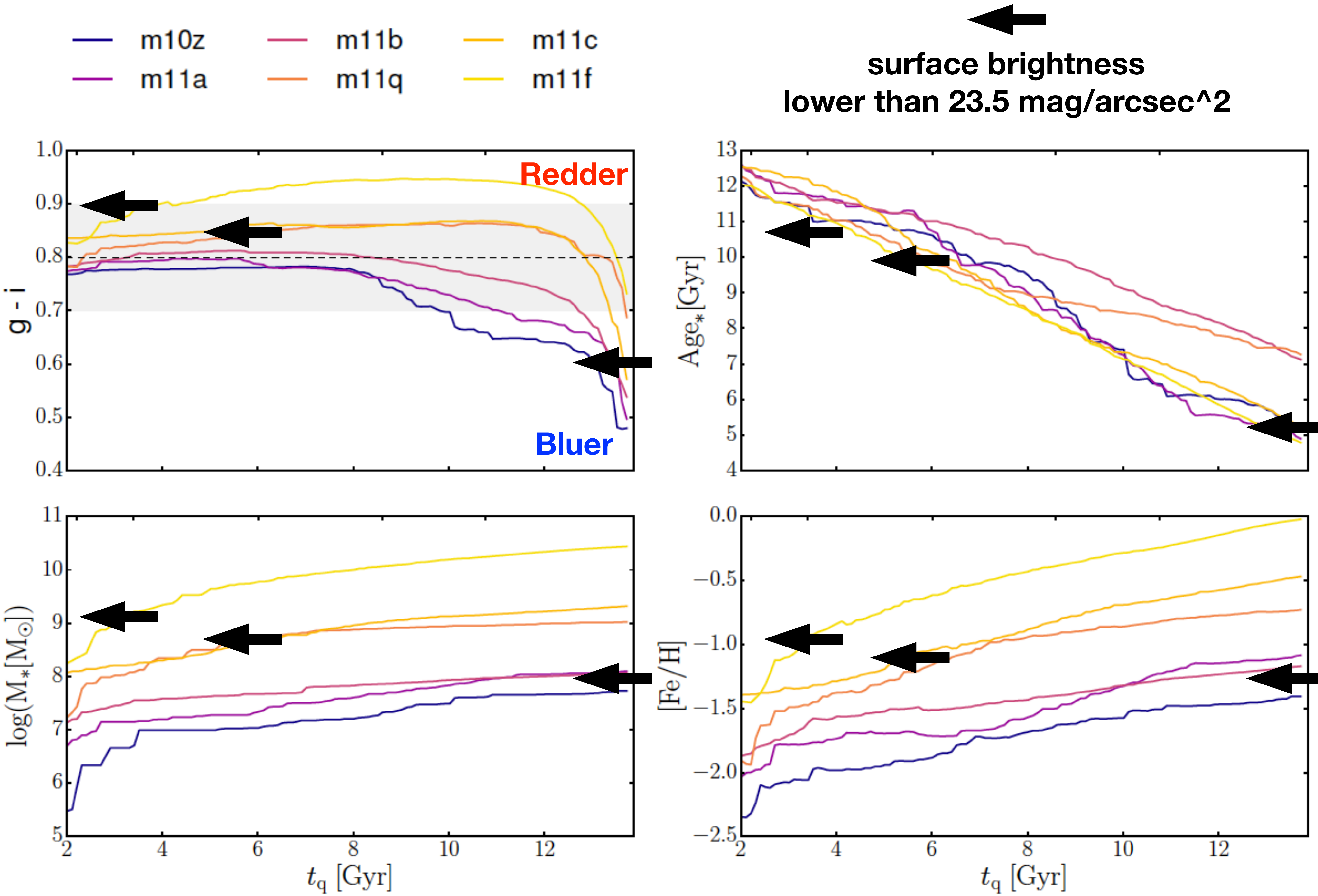

Distinct properties of UDGs due to different quenching time t_q

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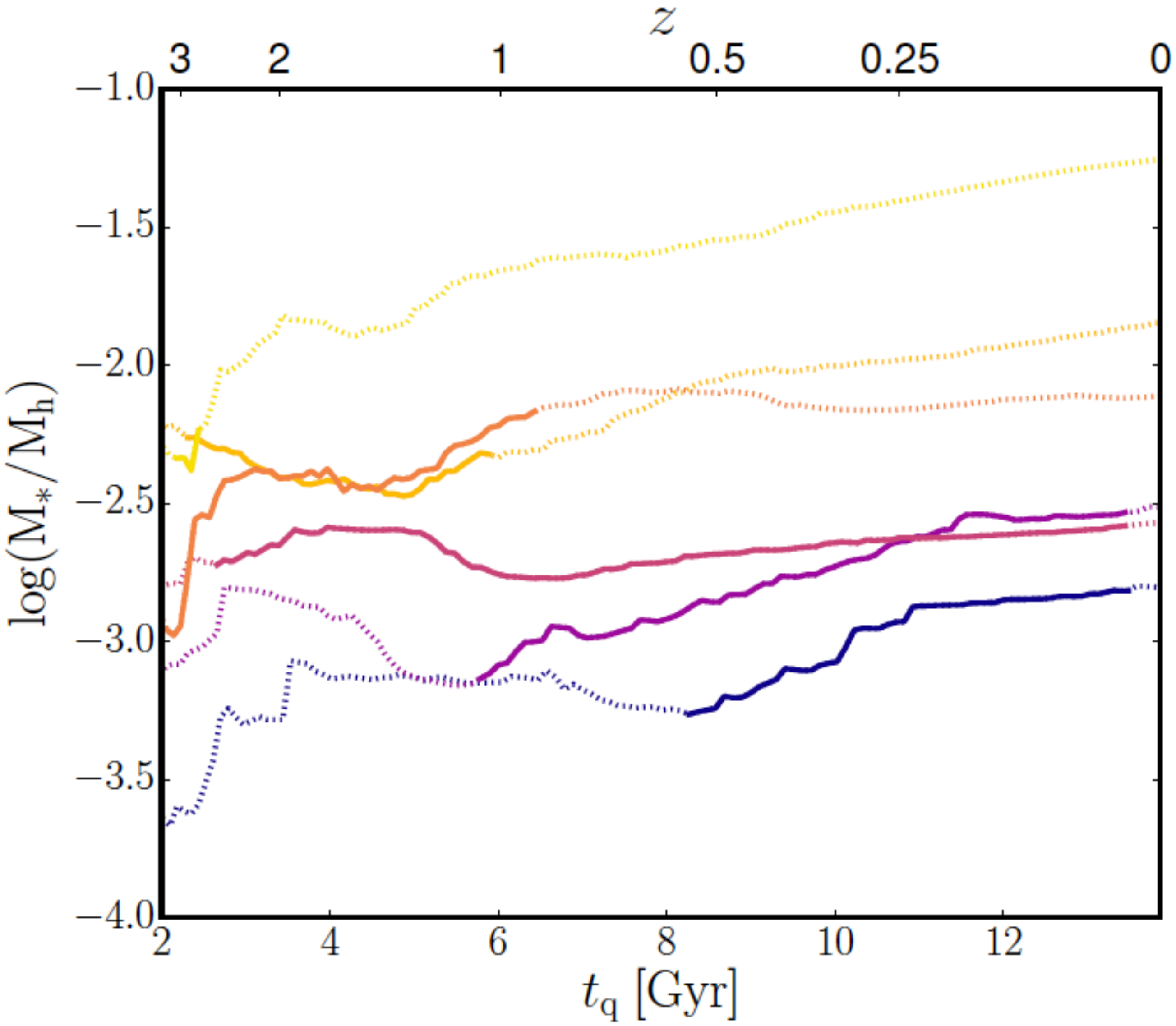
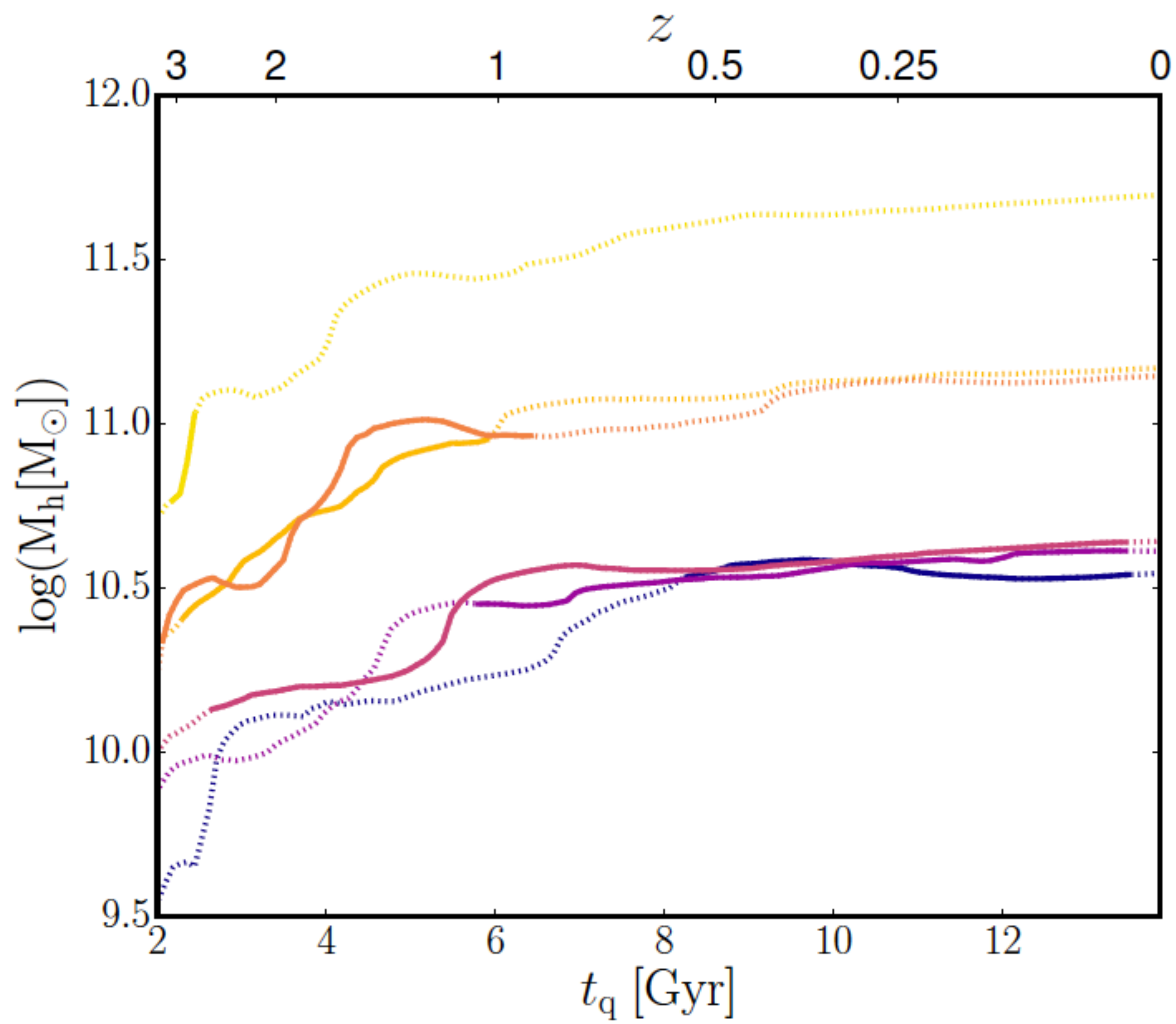
Do UDGs have overmassive halos? No.

Solid: μ >23.5 mag/arcsec^2; Mg<-12.5 mag; (to match Coma UDGs)



Normal M_{star}-M_{halo} ratio ~ field dwarf galaxies



$M_{halo}(t_q)$~1e10-11Msun

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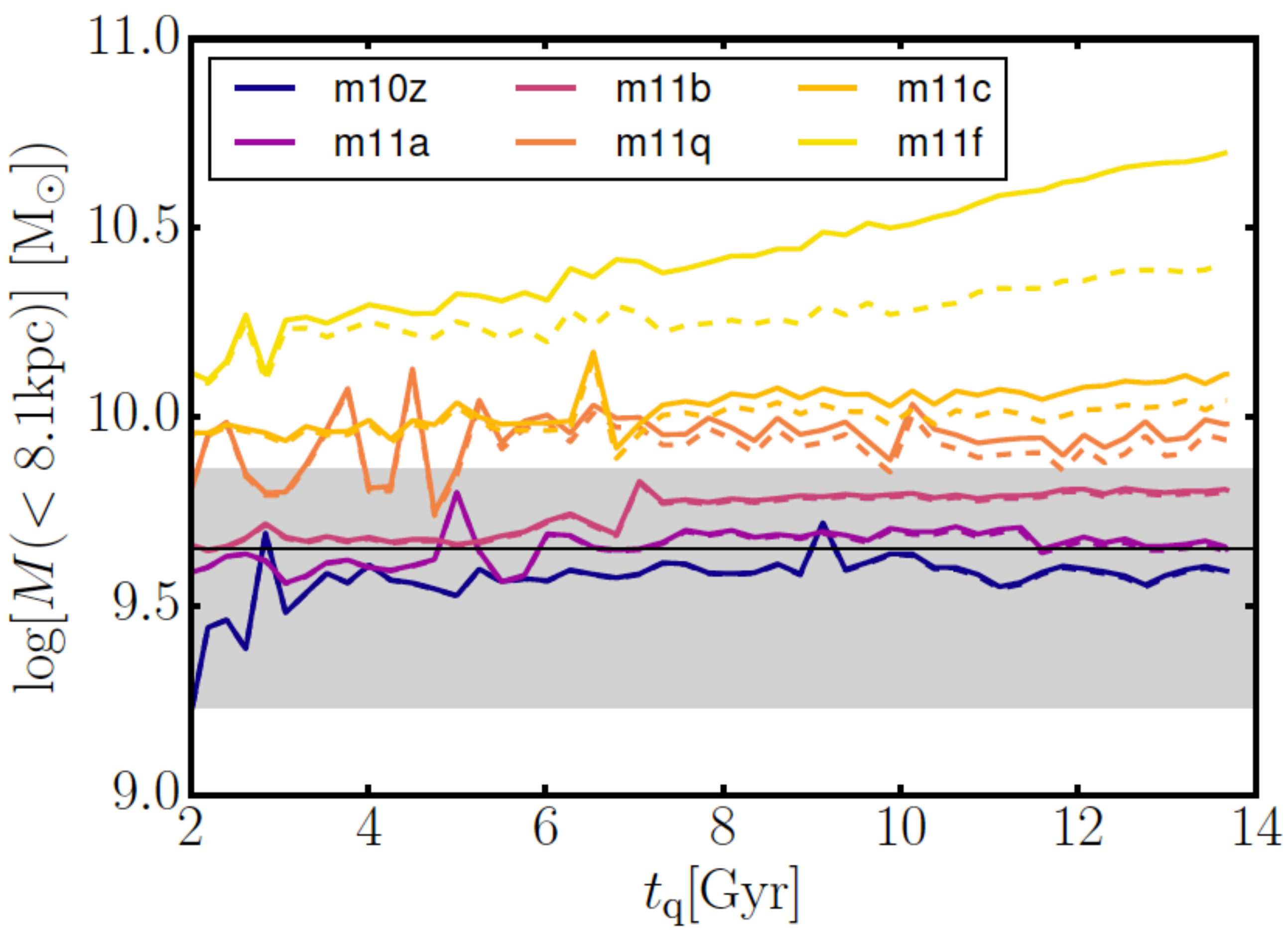
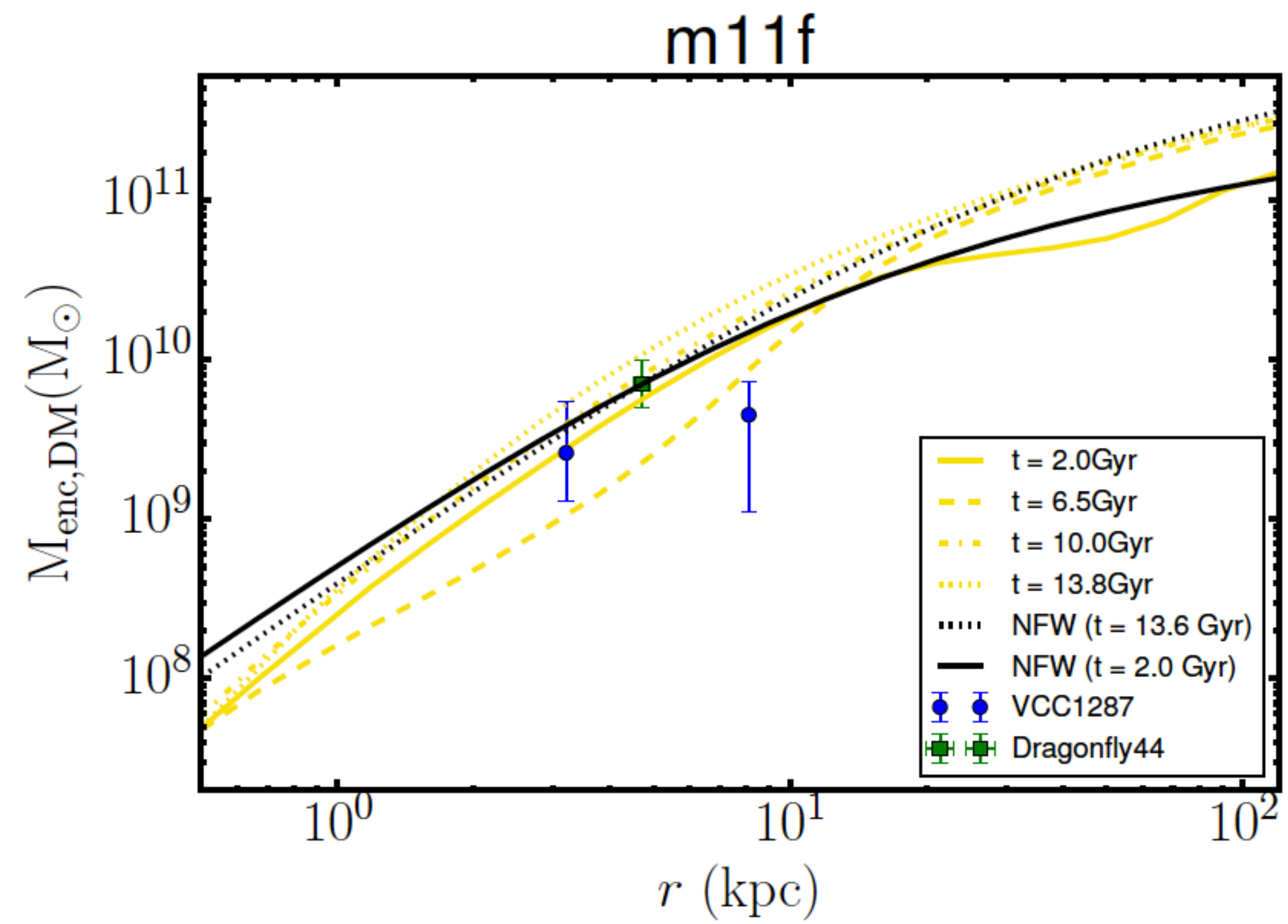
Why inner halo mass is so big: it does not change at late times

Dashed: DM
Solid: DM+star

Grey region: VCC1287

Data:
Dragonfly44: van Dokkum+15
VCC1287: Beasley+16





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Wetzel & Nagai 15:
"*most halo growth at late cosmic time (z < 2) is not physical but is rather the by-product of an evolving virial radius (**pseudo-evolution**).*"

Explanation for high GC numbers of red UDGs

Hypothesis:

(a) GC number directly proportional to $M_{halo}(z>3)$

(b) a minimum $M_{halo}(z>3)$ that can hold a GC

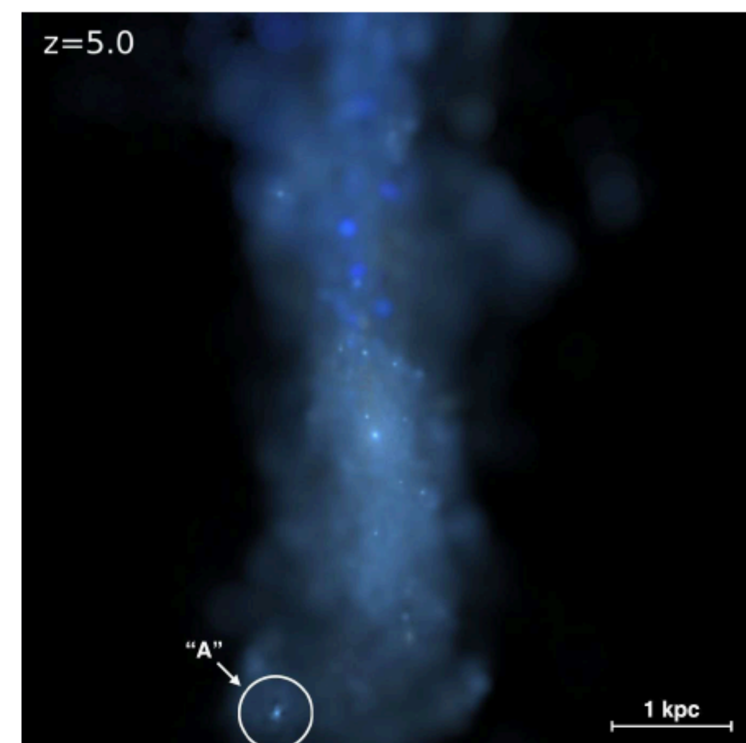
(c) Stellar mass, halo mass and GC number do not change much after quenching;

-> Higher GC number to stellar mass at higher z

- quenching time of red UDGs-> constraints on GC formation

See Boylan-Kolchin 17 for an interesting proposal for the GC halo connection

UDG: a galaxy fossil?



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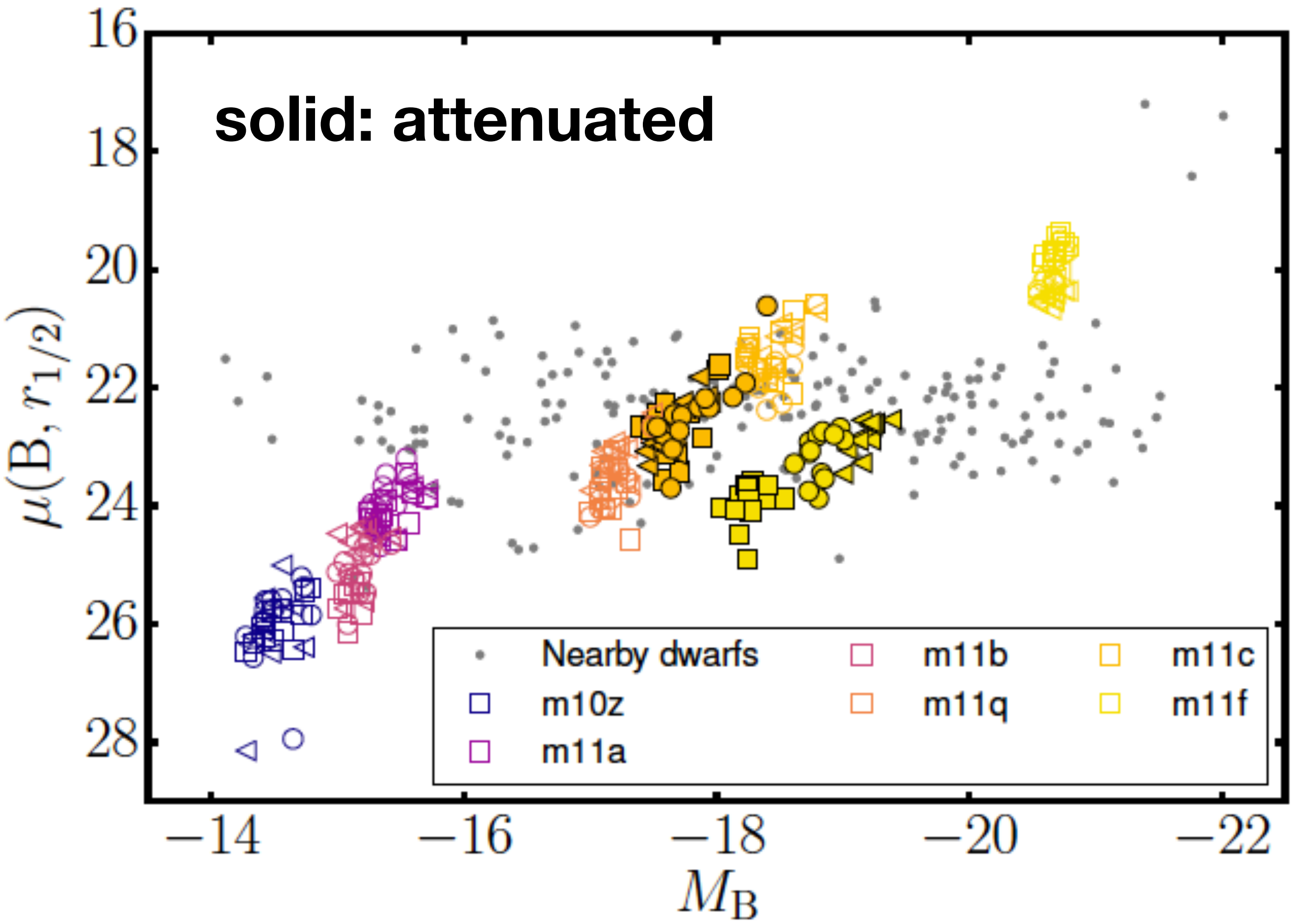
Blue/field UDGs in our simulations

Jansen+00



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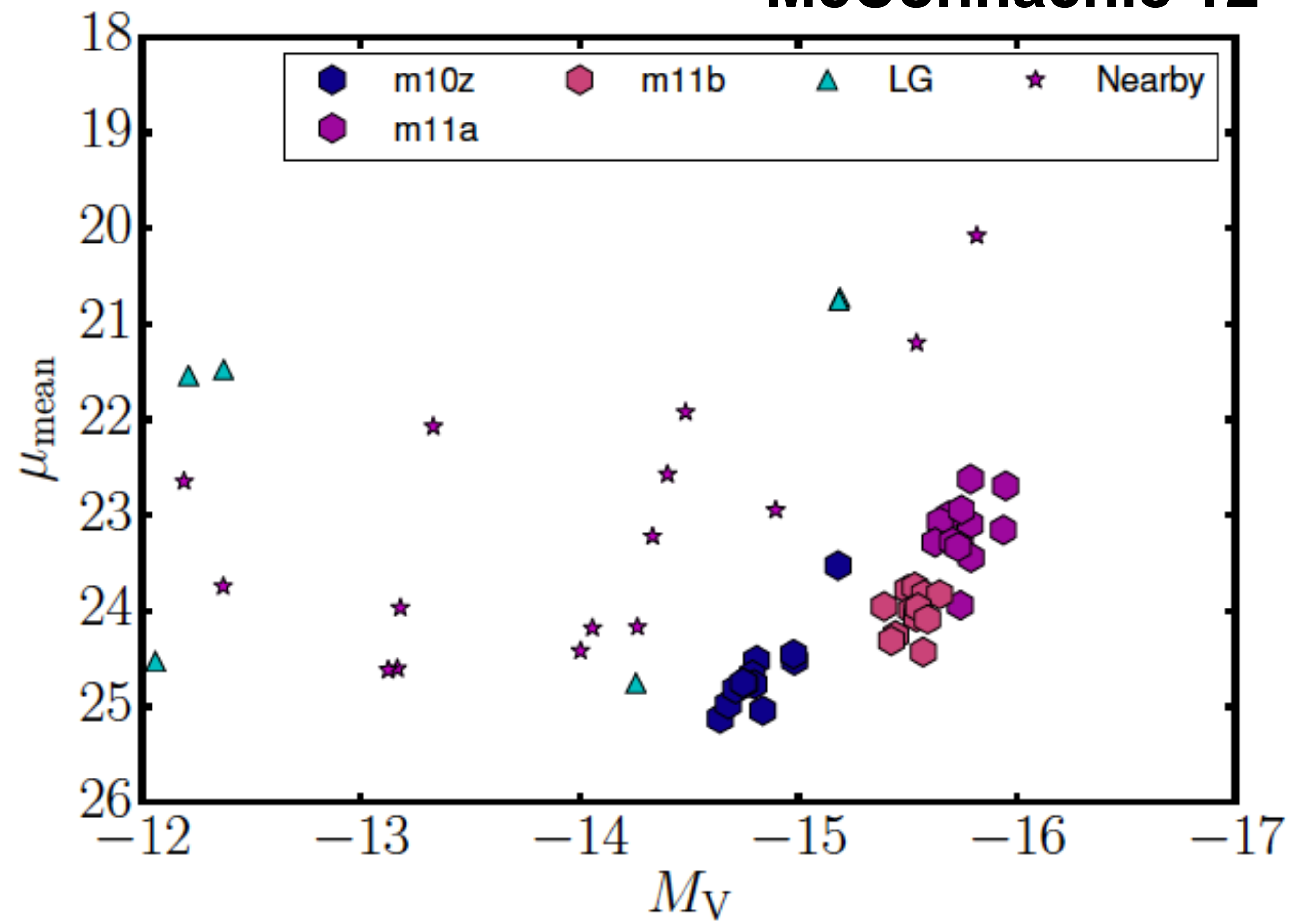

Without quenching: our galaxies are low surface brightness dwarf galaxies -> blue UDGs?

- How to make a compact dwarf galaxy?

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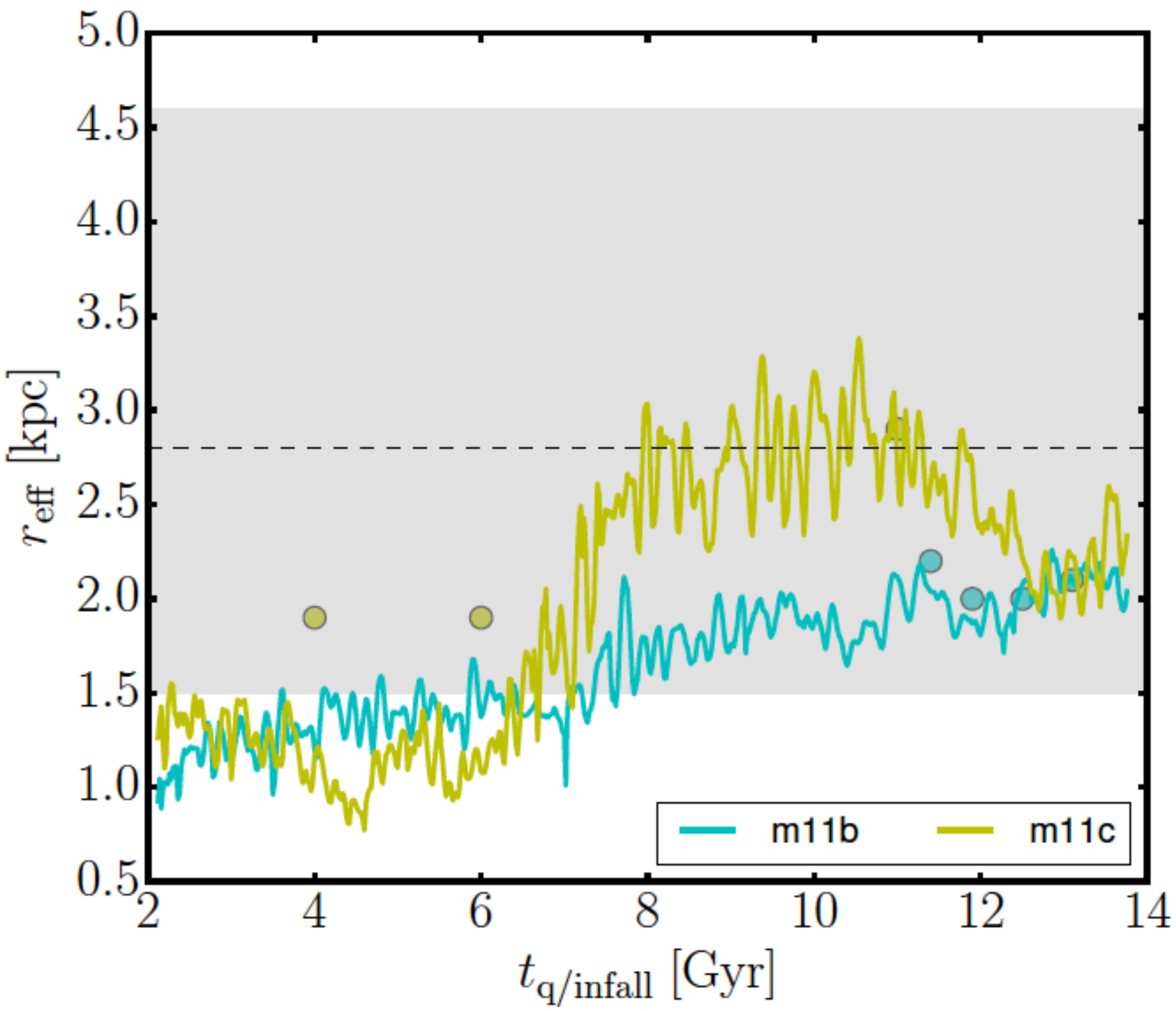
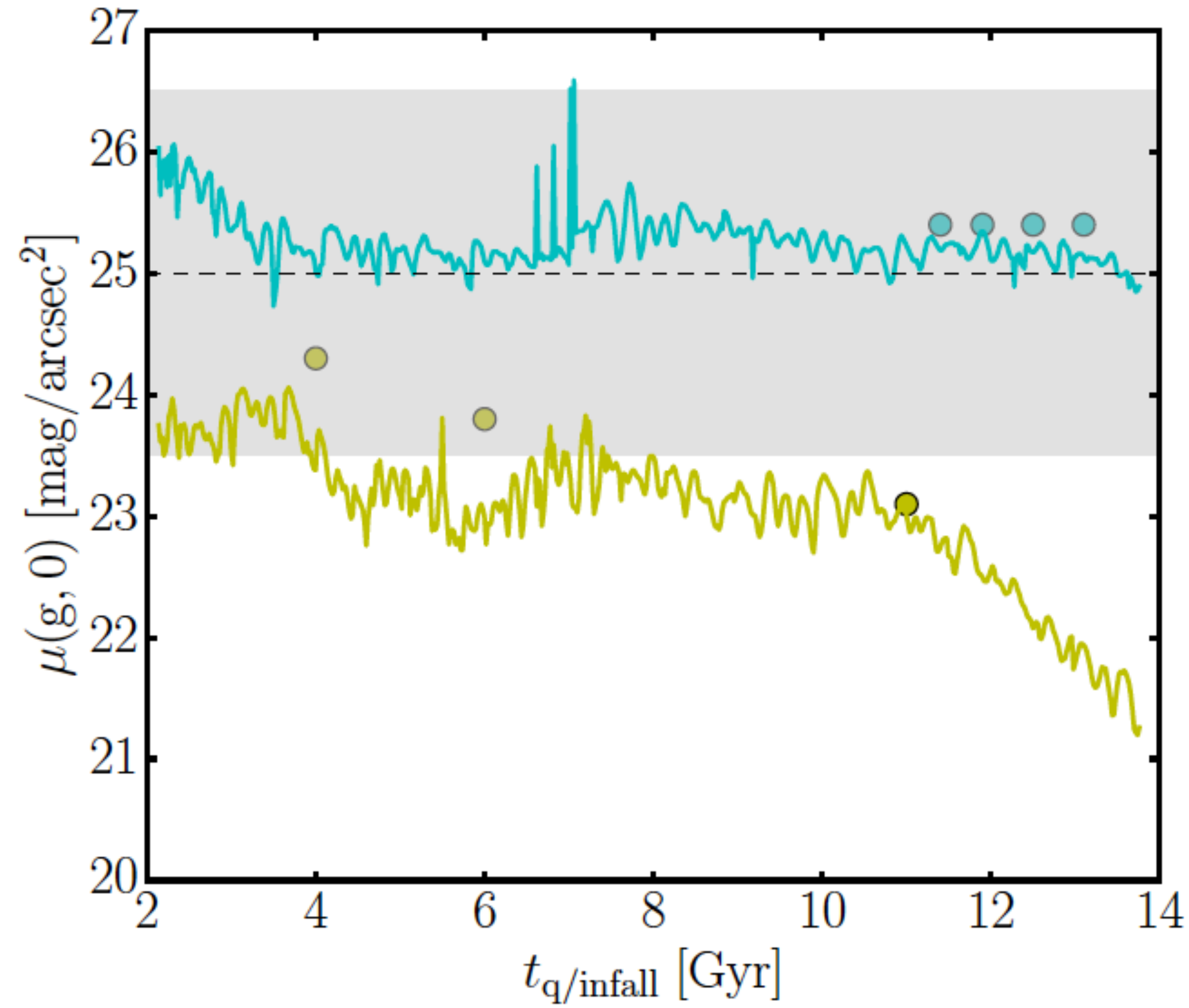
Gas removal simulations





Artificially add velocity 1000km/s to all gas
at cosmic time t_q
& evolve in the field environment

Lines: pro-process with FSPS
points: gas removal simulations

Conclusions

- *Recipe of red UDGs*:

    A. Ms~1e8M_{sun} galaxies expanded by stellar feedback

    B. Quenched in the cluster environment

    C. Gas removal is secondary

- *No* over-massive DM halos but due to early quenching:

    1. High inner DM mass

    2. Rich in GCs

- *Future work*:

    A. High resolution dwarf galaxy simulation

        1. m_{gas} ~ 200M_{sun}

        2. Producing GCs?

        3. Compact galaxies?

    B. Modelling the interactions between galaxy cluster (group) and UDGs

        - Ram pressure/tidal stripping, etc.

We thank the Lorentz workshop organisers.