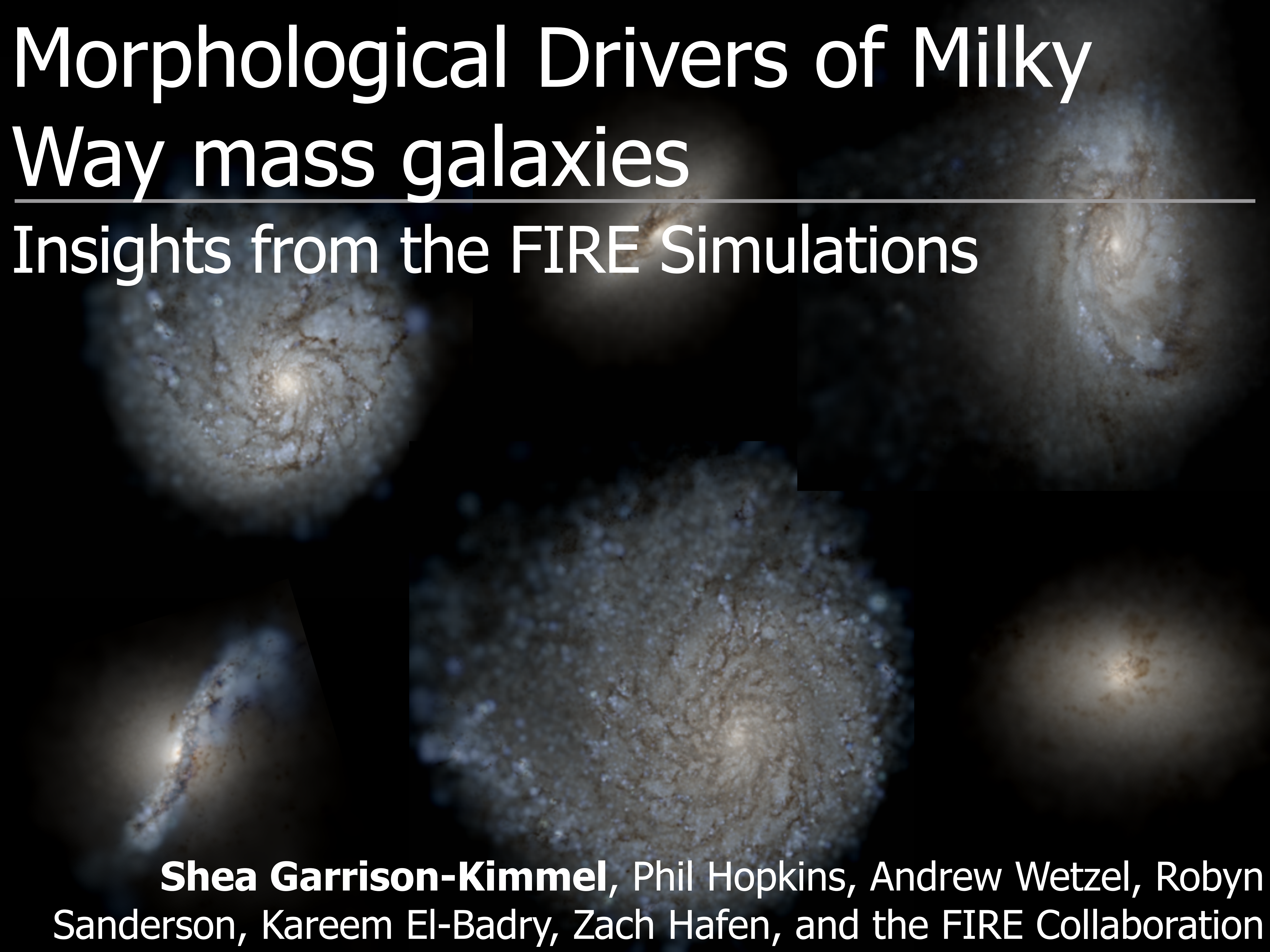
Morphological Drivers of Milky Way mass galaxies

Insights from the FIRE Simulations



Shea Garrison-Kimmel, Phil Hopkins, Andrew Wetzel, Robyn Sanderson, Kareem El-Badry, Zach Hafen, and the FIRE Collaboration

FIRE-2 MW-mass sample

Fifteen galaxies simulated with the FIRE-2 models for star formation and feedback

Eight galaxies in LG-like pairs; seven isolated galaxies including three from the Latte suite (Wetzel+2016)

Baryonic particle masses
$7\text{–}55 \times 10^3\ M_{\rm sun}$

stellar softening lengths
$\lesssim 20$ pc

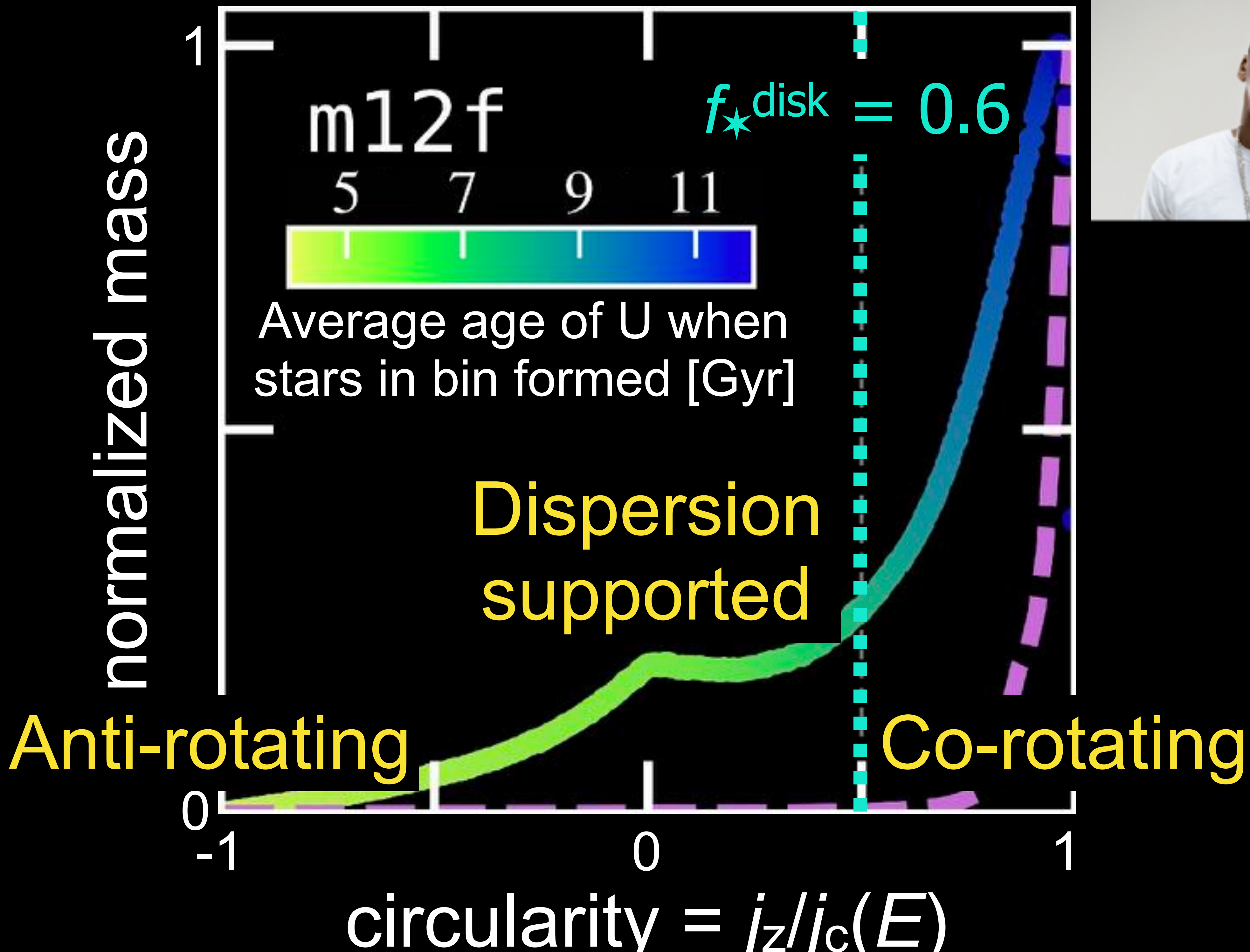
$0.86 \lesssim M_{\rm halo} \lesssim 1.95 \times 10^{12}\ M_{\rm sun}$

$0.39 \lesssim M_{\rm star} \lesssim 1.5 \times 10^{11}\ M_{\rm sun}$

$2.5 \lesssim R_{\rm star} \lesssim 17.5$ kpc

Hopkins+2017a,b

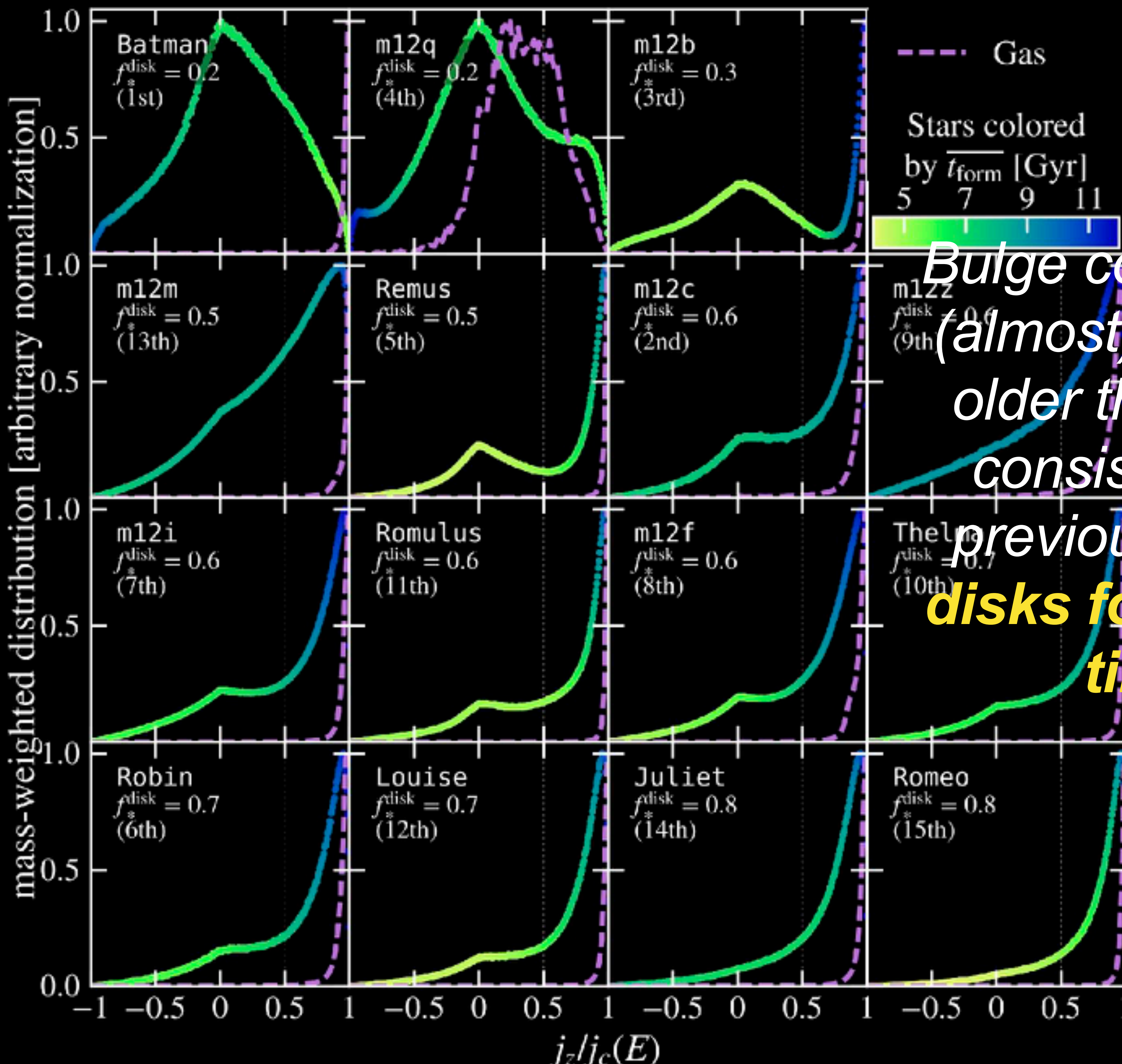
Quantifying morphology: j_z/j_{circ}



j_z/j_{circ} relates the component of J aligned with J_{tot} to what it *would be* for a circular orbit aligned with the disk

Define: $f_\star^{disk}$ = fraction of stellar mass with $j_z/j_c(E) > 0.5$

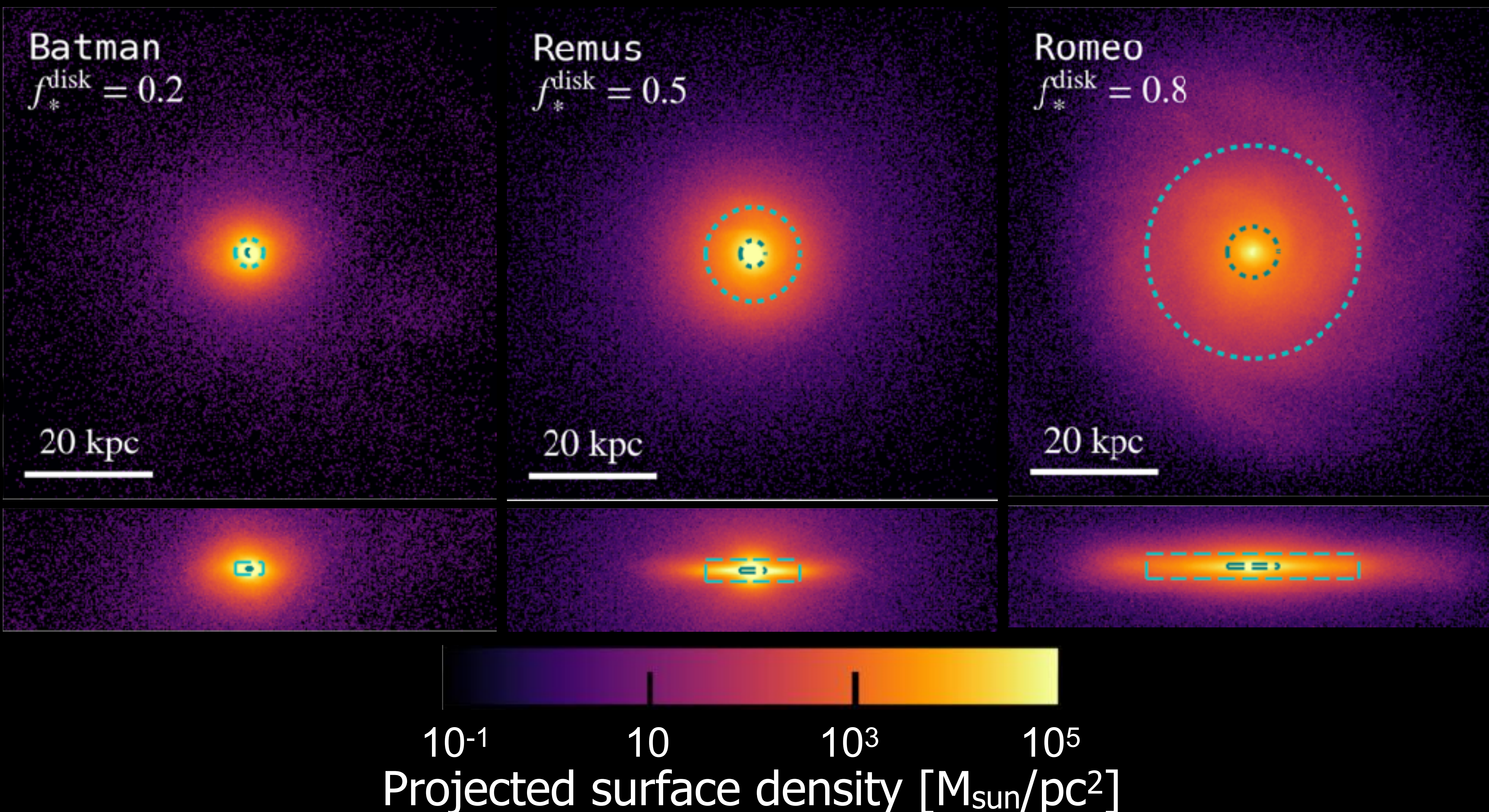
Sample includes 0.2 ≦ f★$_{disk}$ ≦ 0.8

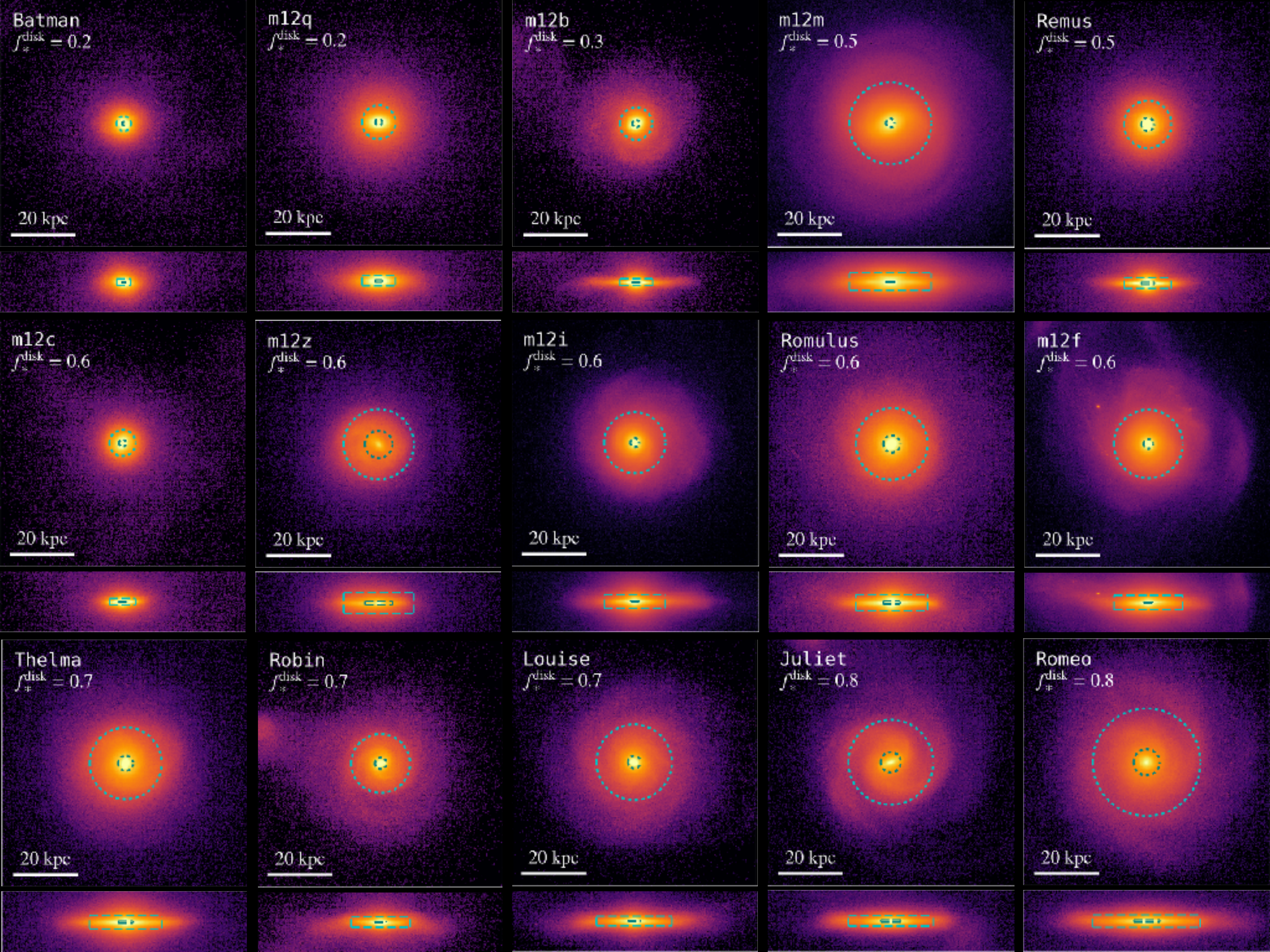


Bulge components (almost) uniformly older than disks, consistent with previous results: ***disks form at late times***

Quantifying morphology: $R_\star$

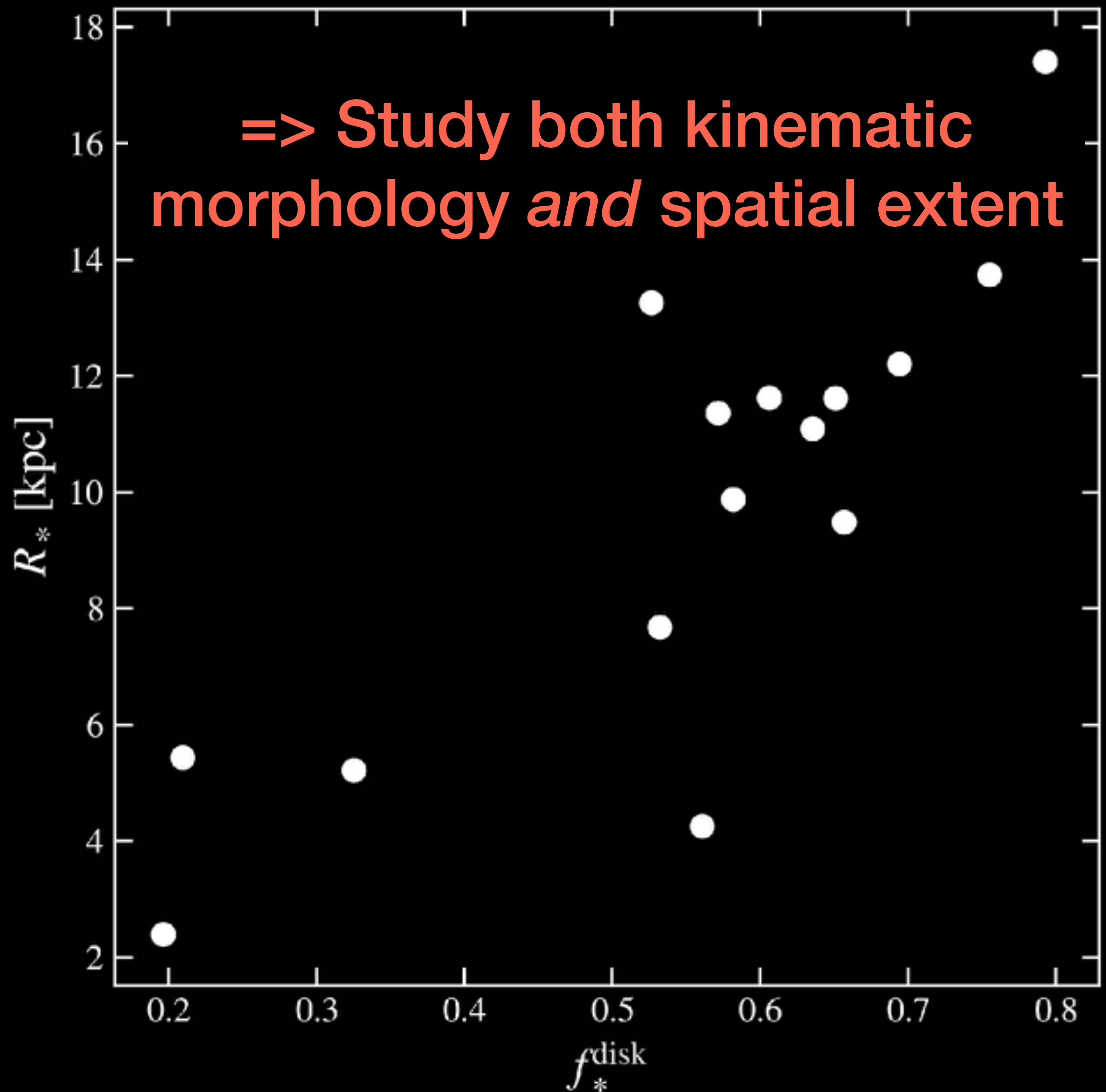
Define: R^* = 2D radius that contains 90% of M_{star}





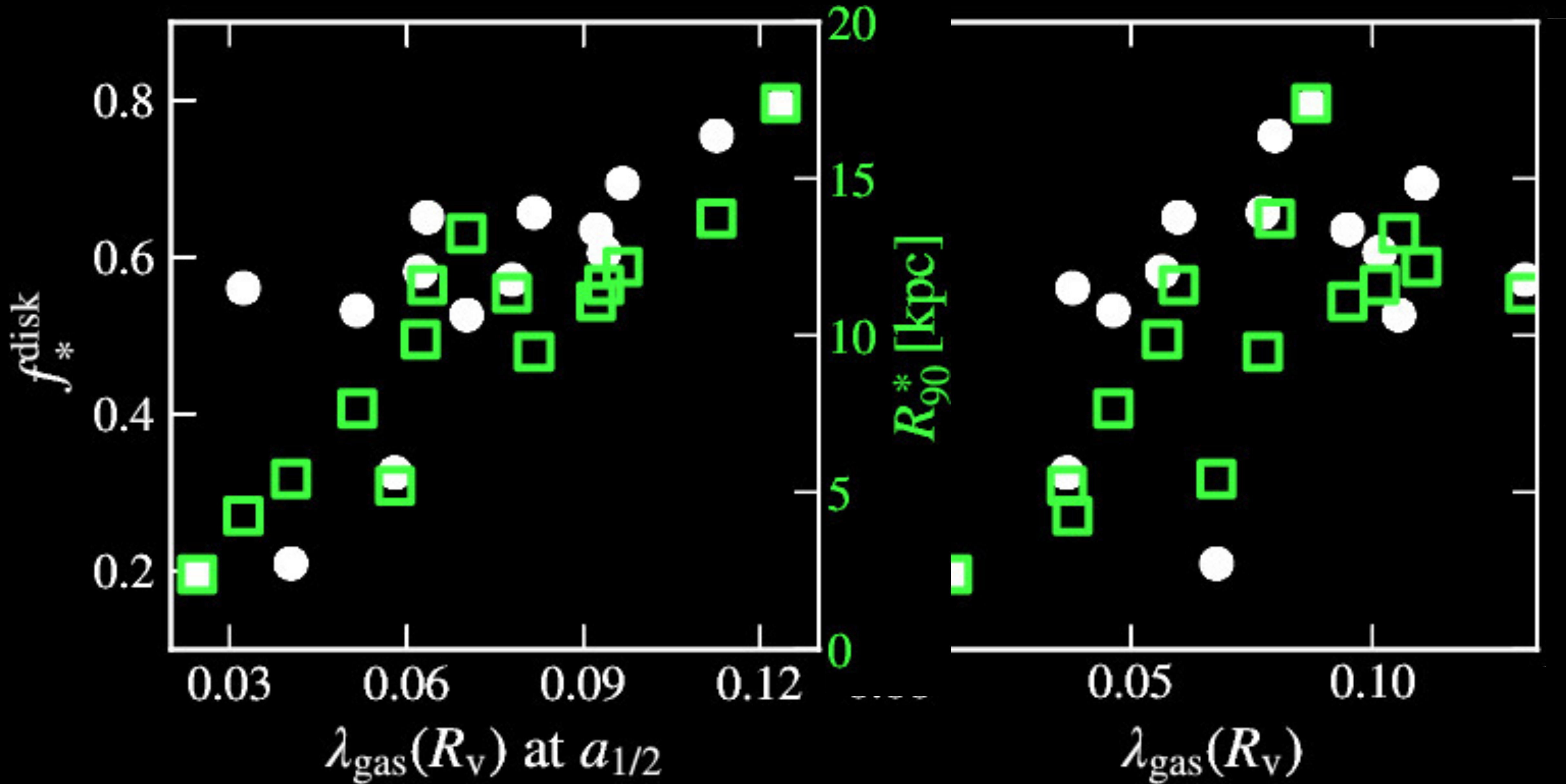
Batman
$f_*^{\rm disk} = 0.2$
20 kpc
m12q
$f_*^{\rm disk} = 0.2$
20 kpc
m12b
$f_*^{\rm disk} = 0.3$
20 kpc
m12m
$f_*^{\rm disk} = 0.5$
20 kpc
Remus
$f_*^{\rm disk} = 0.5$
20 kpc
m12c
$f_*^{\rm disk} = 0.6$
20 kpc
m12z
$f_*^{\rm disk} = 0.6$
20 kpc
m12i
$f_*^{\rm disk} = 0.6$
20 kpc
Romulus
$f_*^{\rm disk} = 0.6$
20 kpc
m12f
$f_*^{\rm disk} = 0.6$
20 kpc
Thelma
$f_*^{\rm disk} = 0.7$
20 kpc
Robin
$f_*^{\rm disk} = 0.7$
20 kpc
Louise
$f_*^{\rm disk} = 0.7$
20 kpc
Juliet
$f_*^{\rm disk} = 0.8$
20 kpc
Romeo
$f_*^{\rm disk} = 0.8$
20 kpc

Comparing morphology measures



Kinematic ($f_\star^{\rm disk}$) and spatial ($R_\star$) correlated, but lots of scatter

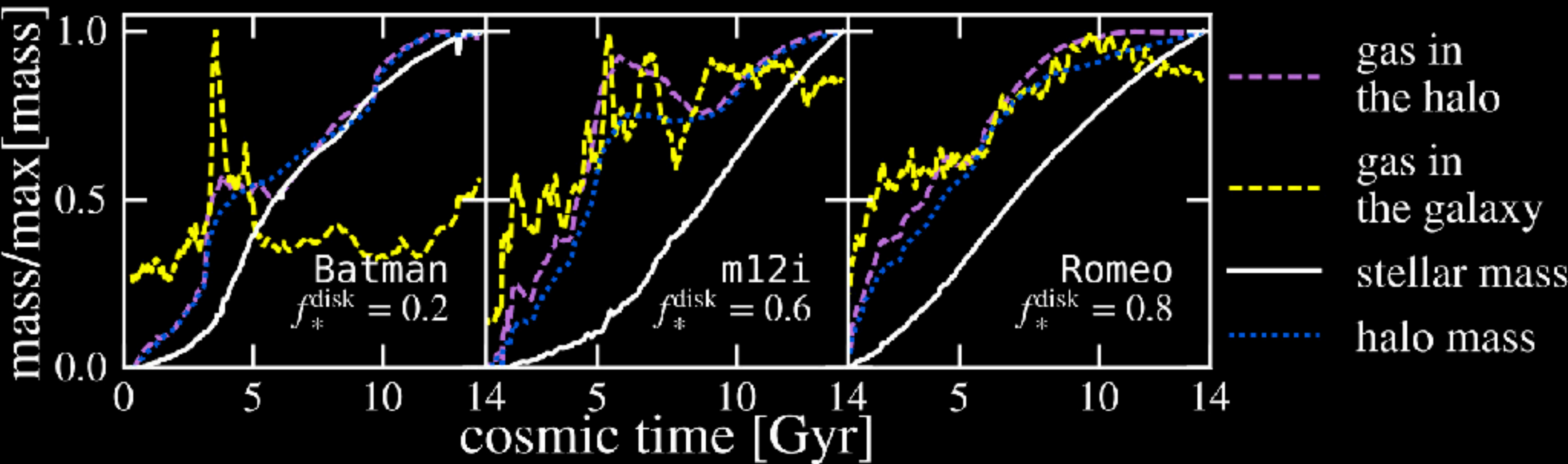
Disks form out of spinning gas



Morphology correlated with gas spin when the galaxy was forming stars

Growth of the galaxy and its halo

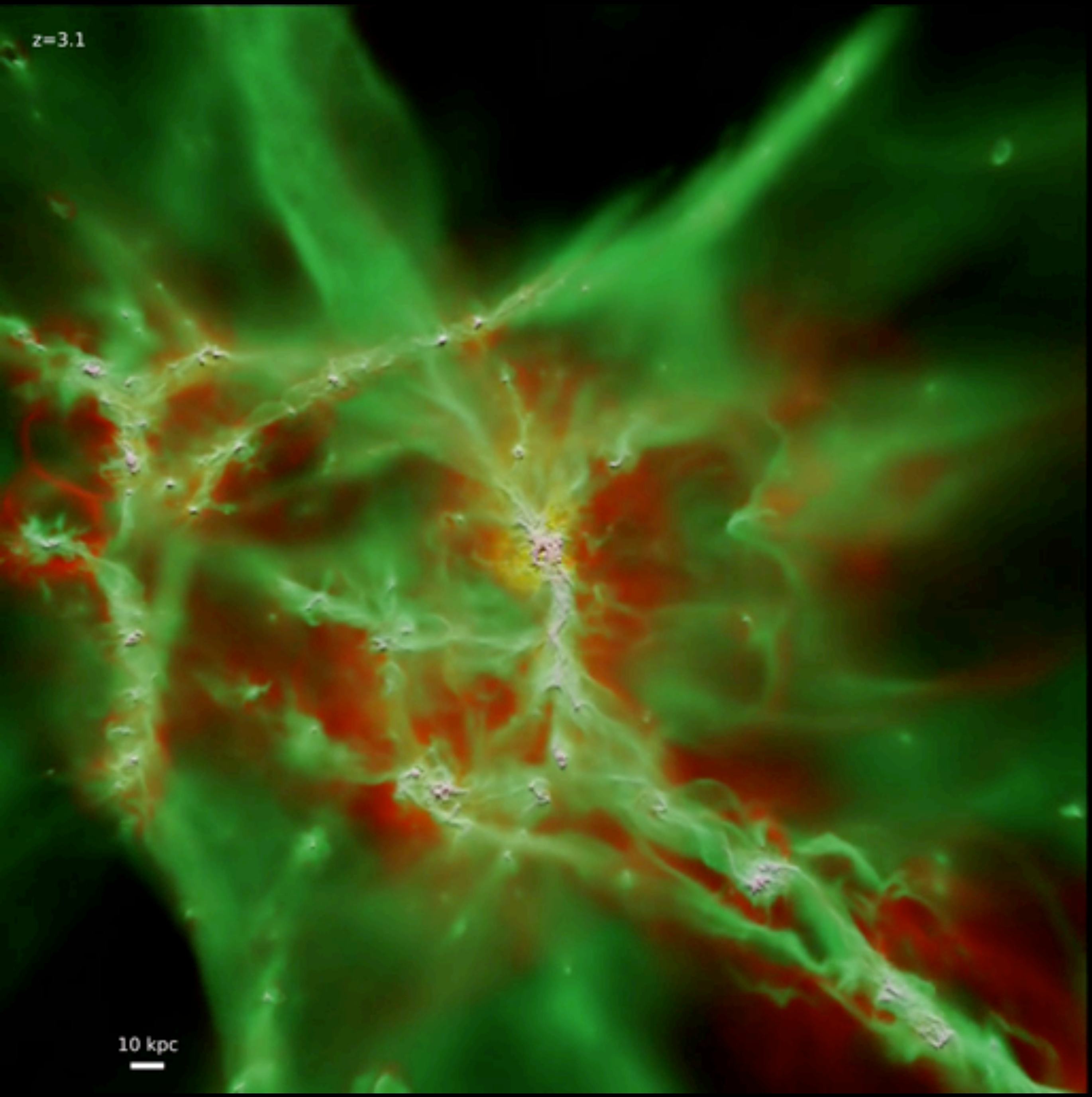
Evolutionary histories

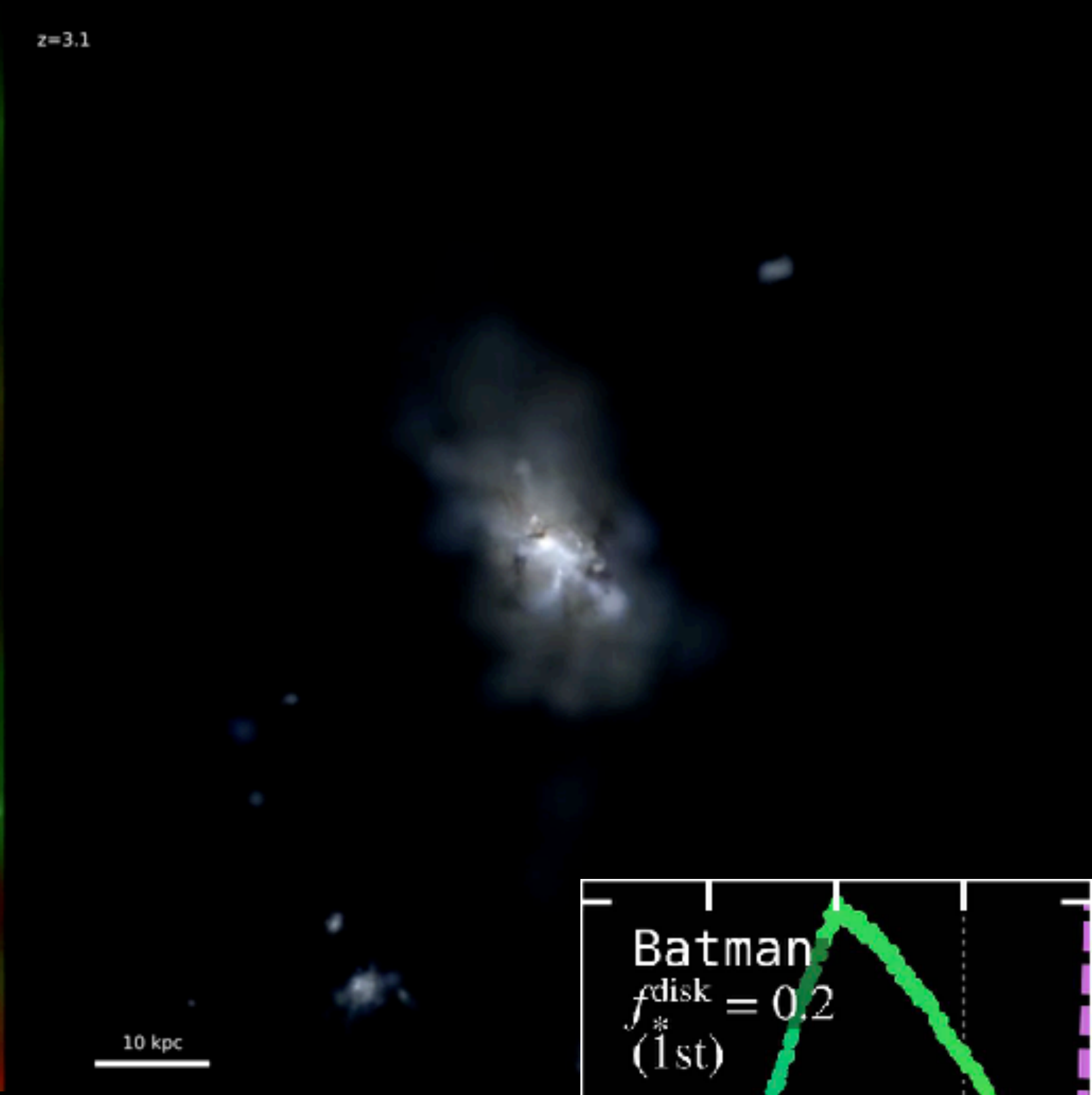


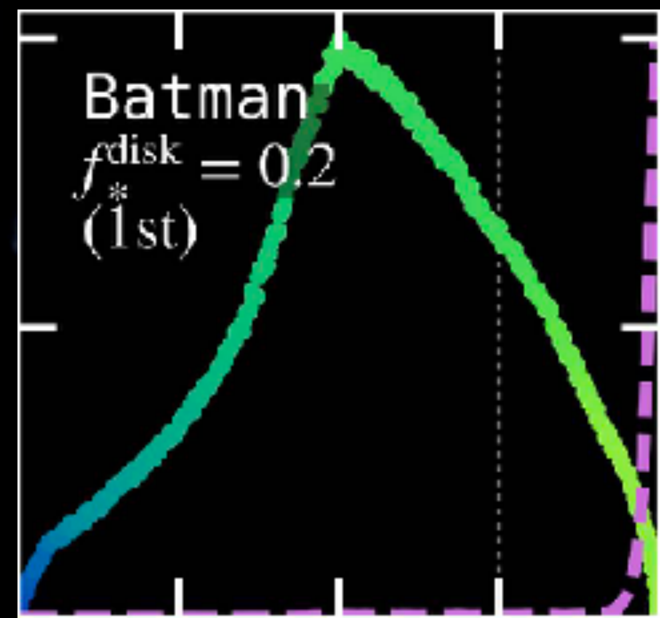
Every galaxy has a story

Every galaxy has a story: Batman

The Dark Knight Rises

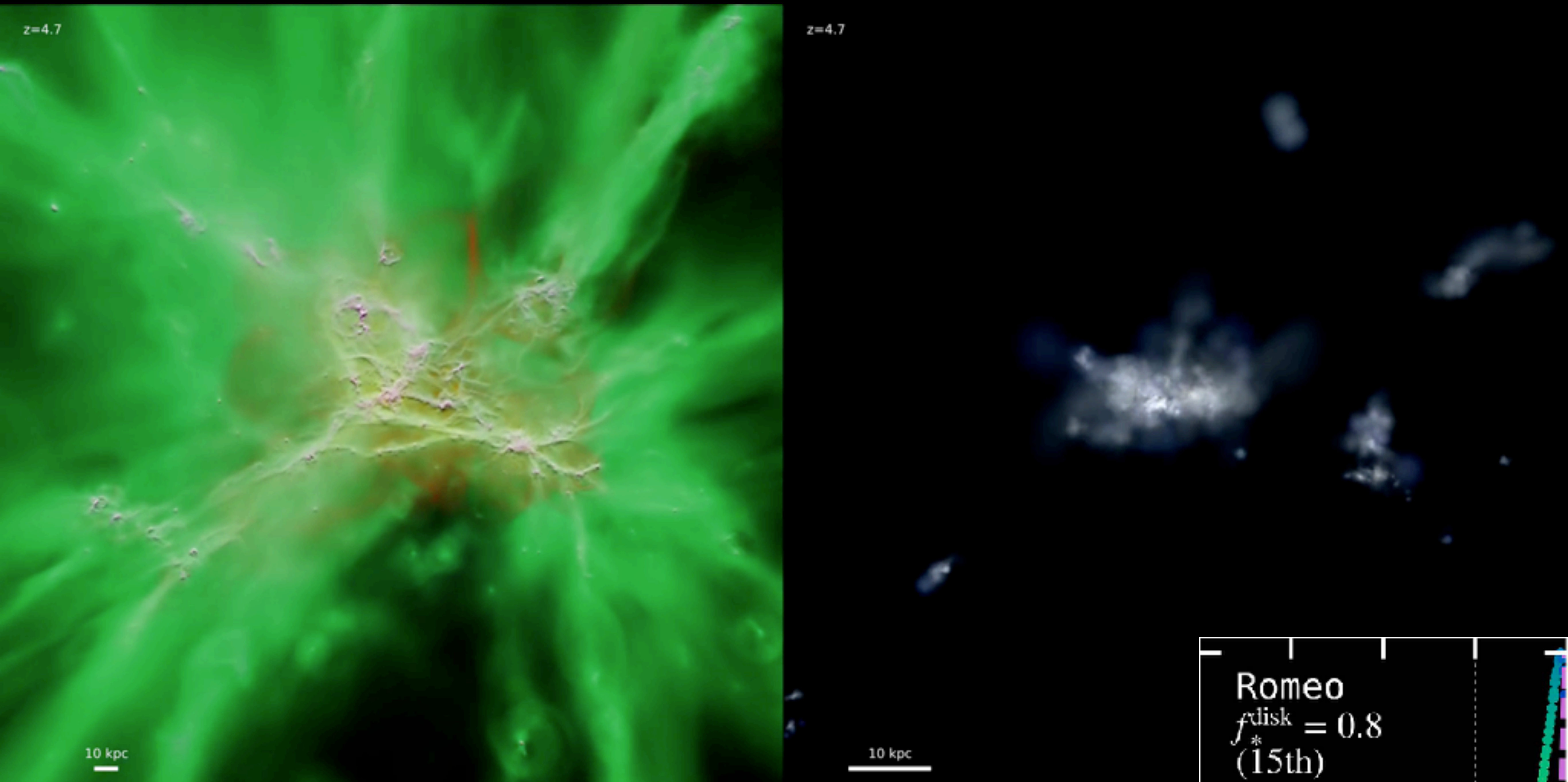


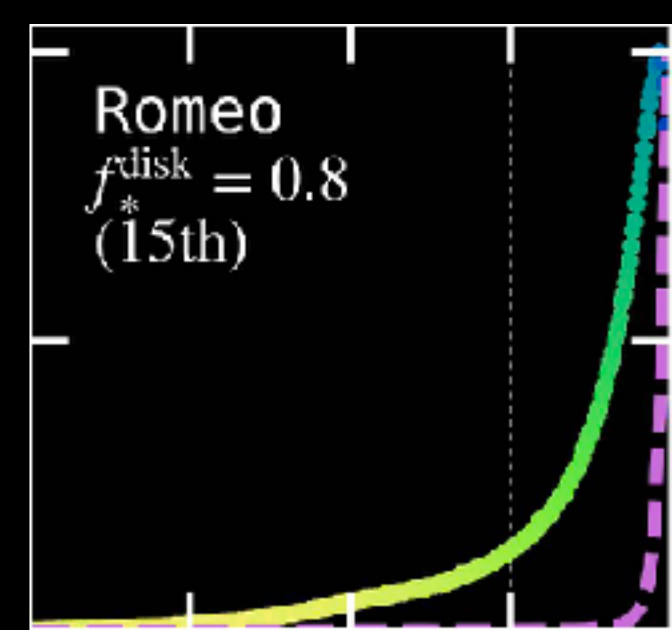




Double merger funnels gas to center at z~2 to form bulge; no late-time gas accretion

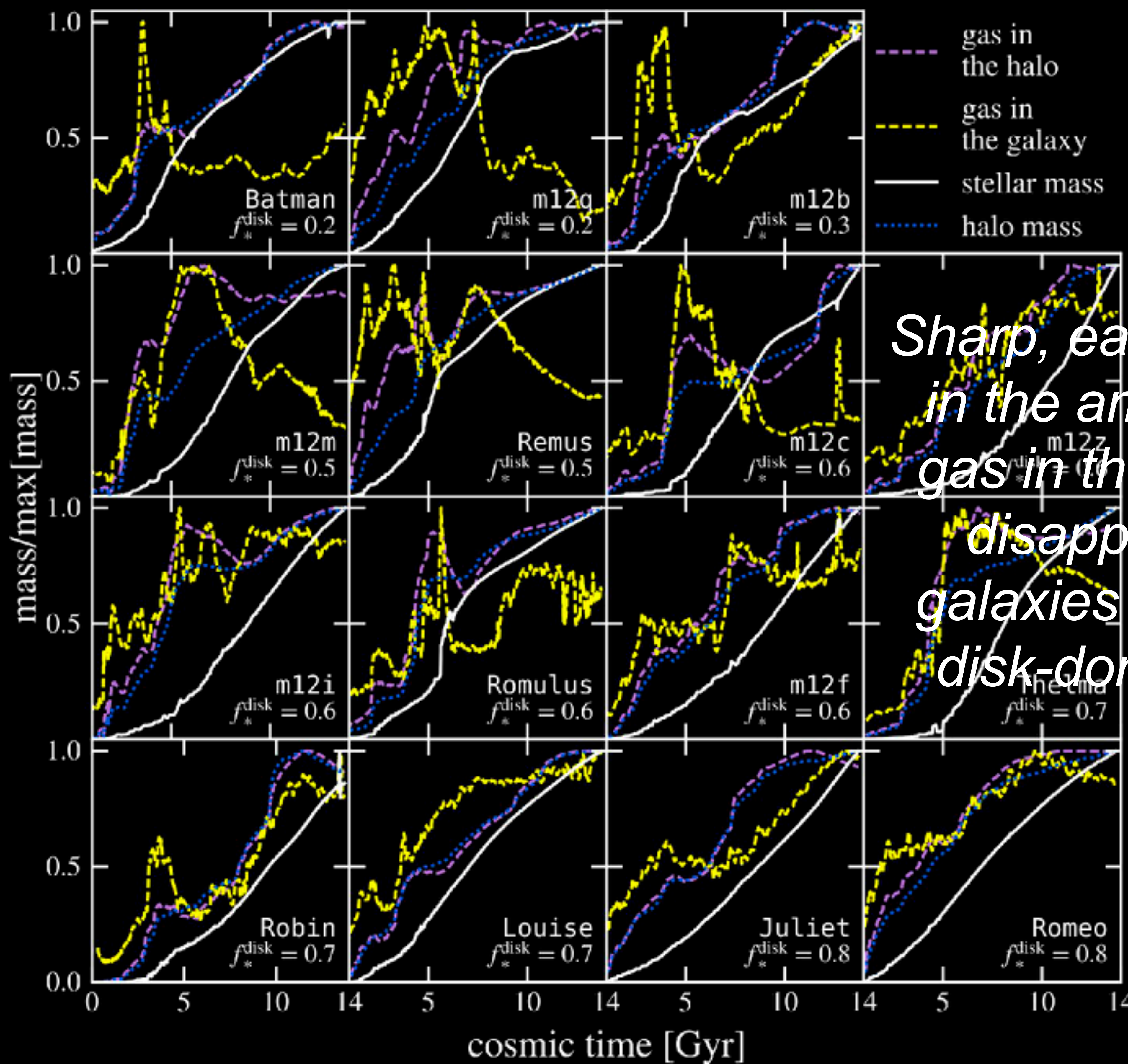
Every galaxy has a story: Romeo





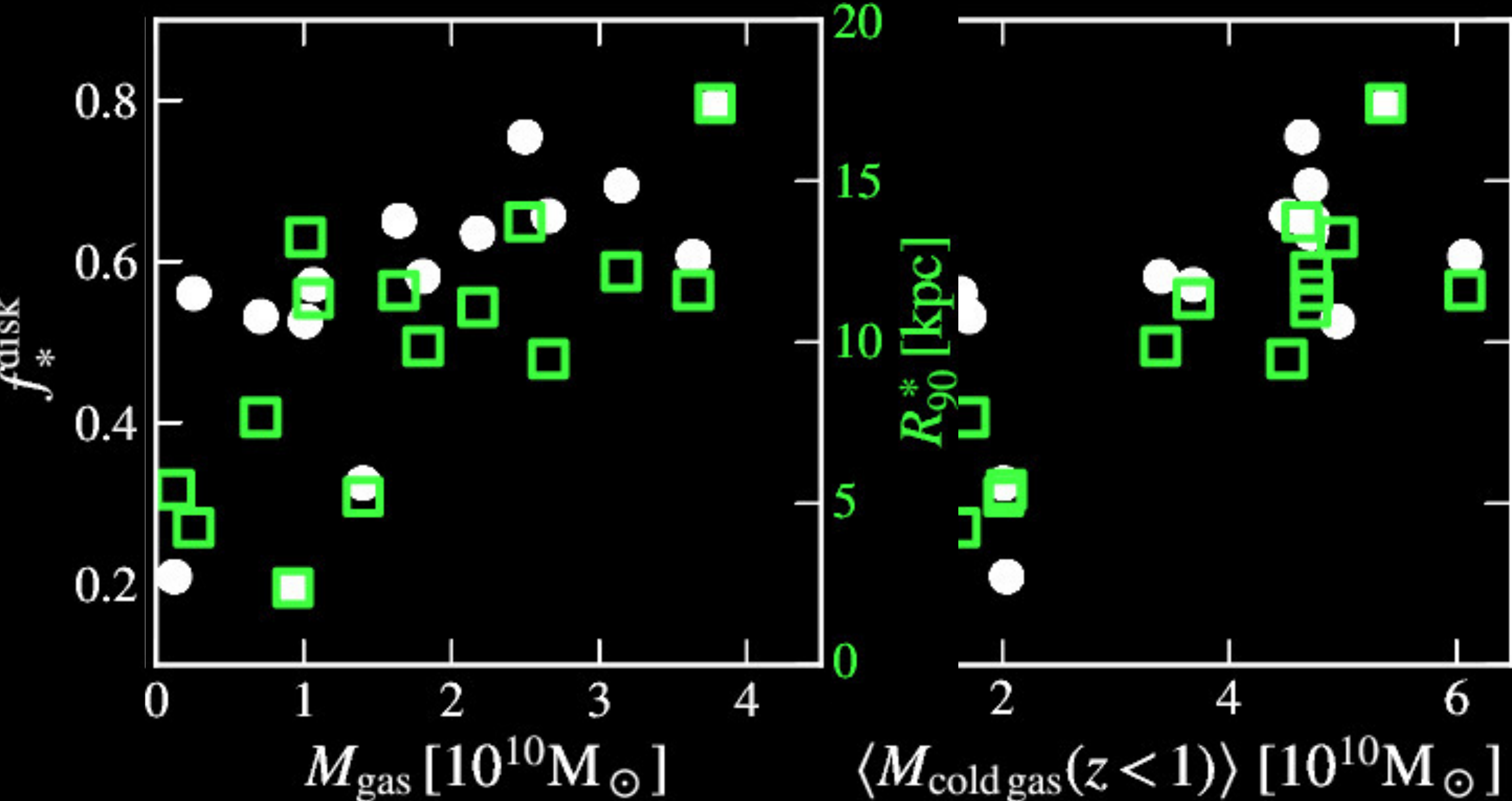
No direct galaxy mergers after *z*~4
Smooth accretion to *z*=0

Every galaxy has a story



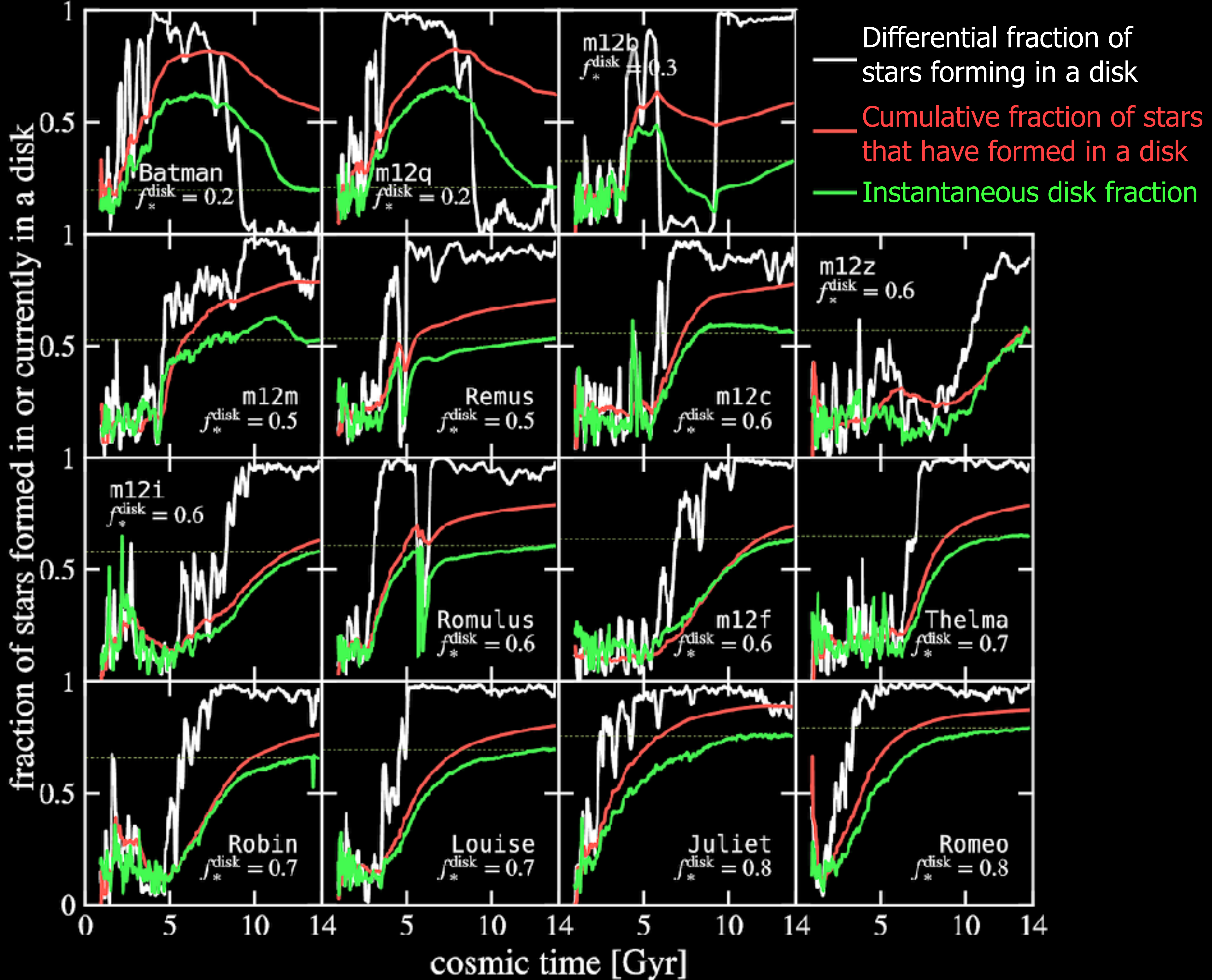
Sharp, early spikes in the amount of gas in the galaxy disappear as galaxies become disk-dominated

Morphology scales with $M_{gas}(z)$



Gas accreted at late times typically has higher angular momentum and forms a disk

The evolution of stellar morphologies


Differential fraction of stars forming in a disk
Cumulative fraction of stars that have formed in a disk
Instantaneous disk fraction
fraction of stars formed in or currently in a disk
cosmic time [Gyr]
Batman $f_*^{disk} = 0.2$
m12q $f_*^{disk} = 0.2$
m12b $f_*^{disk} = 0.3$
m12m $f_*^{disk} = 0.5$
Remus $f_*^{disk} = 0.5$
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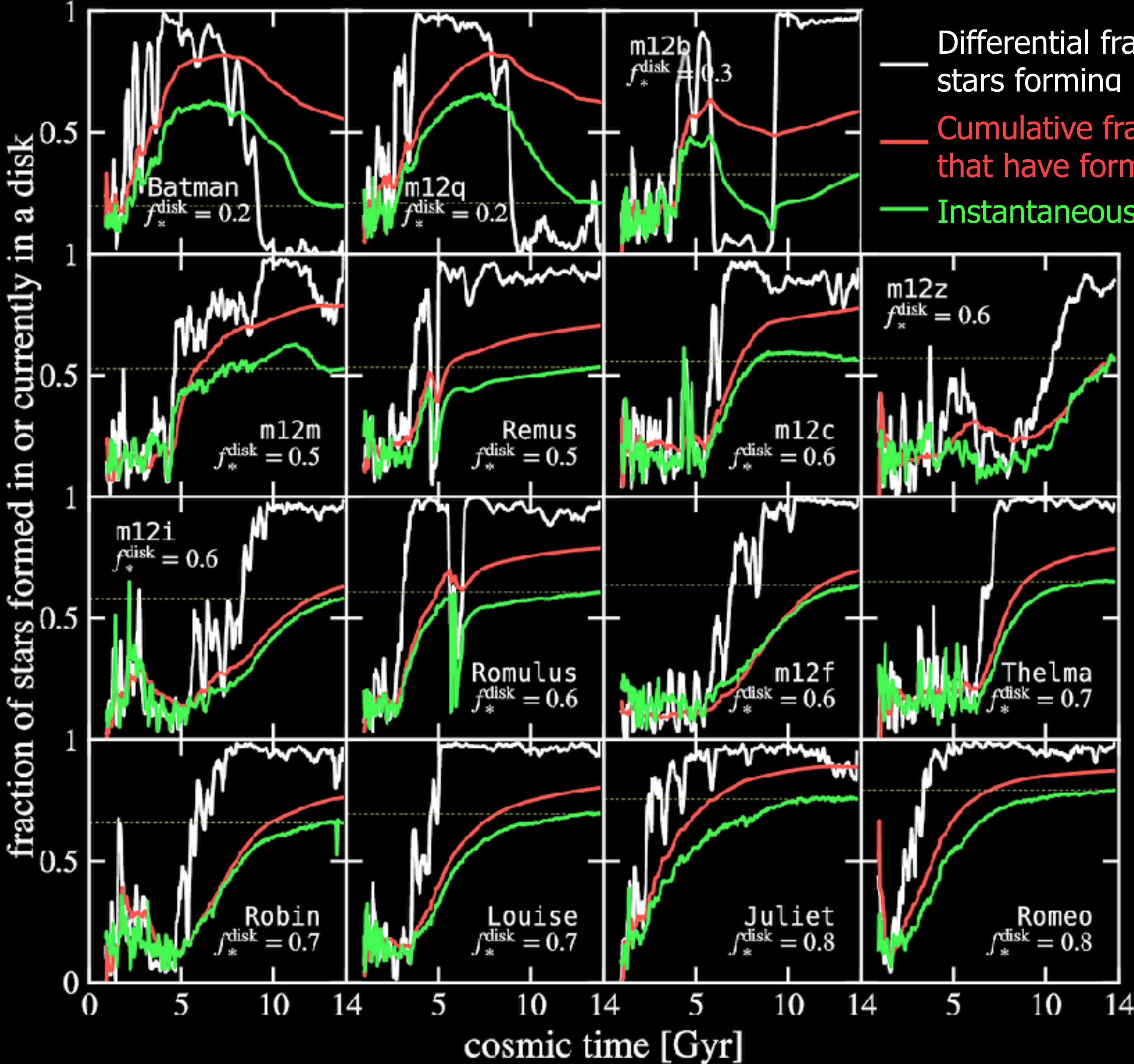


Nearly all stars forming at late times in MW-mass galaxies **form in disks**

60-90% of stars are born in disks overall, even in bulge-dominated systems

Galaxies nearly always become **more disky** with time ($R^\star$ also increasing)

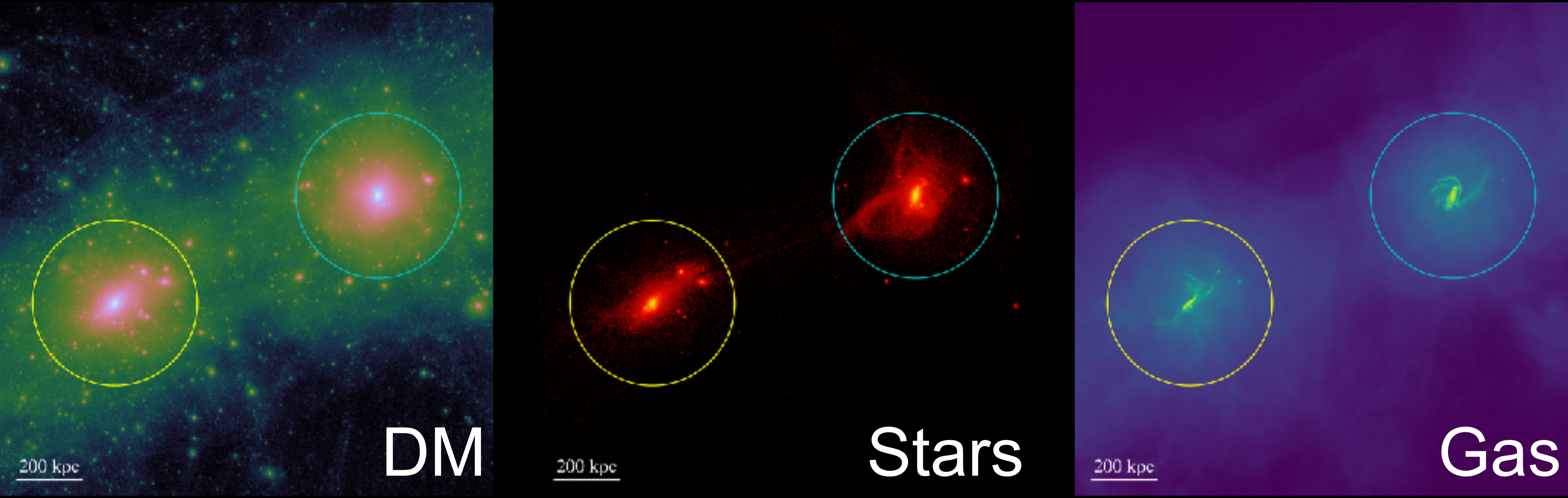
Mergers scramble/destroy disks at early times, but can help build disks if they occur at late times (when they tend to have more *J*)

Summary

- Fifteen MW-mass galaxies on FIRE vary from bulge-dominated to roughly pure disk (defined kinematically)
- Gas spin at high redshift is a good indicator of morphology
- Head-on mergers funnel gas to the center, where it forms massive bulges; galaxies with smoother accretion histories (no direct *galaxy* mergers; maximize their reservoir of star forming gas at late times) tend to be disk-dominated
- Average amount of cold gas in the halo (i.e., fuel for SF) after z=1 well-correlated with morphology
- $\gtrsim$60% of MW stars (+nearly all born at $z \lesssim 1$) *formed* in disks (though not necessarily the disk that exists today), consistent with a picture where stars forming primarily from rotation-supported gas, as is the case at z=0 in all galaxies

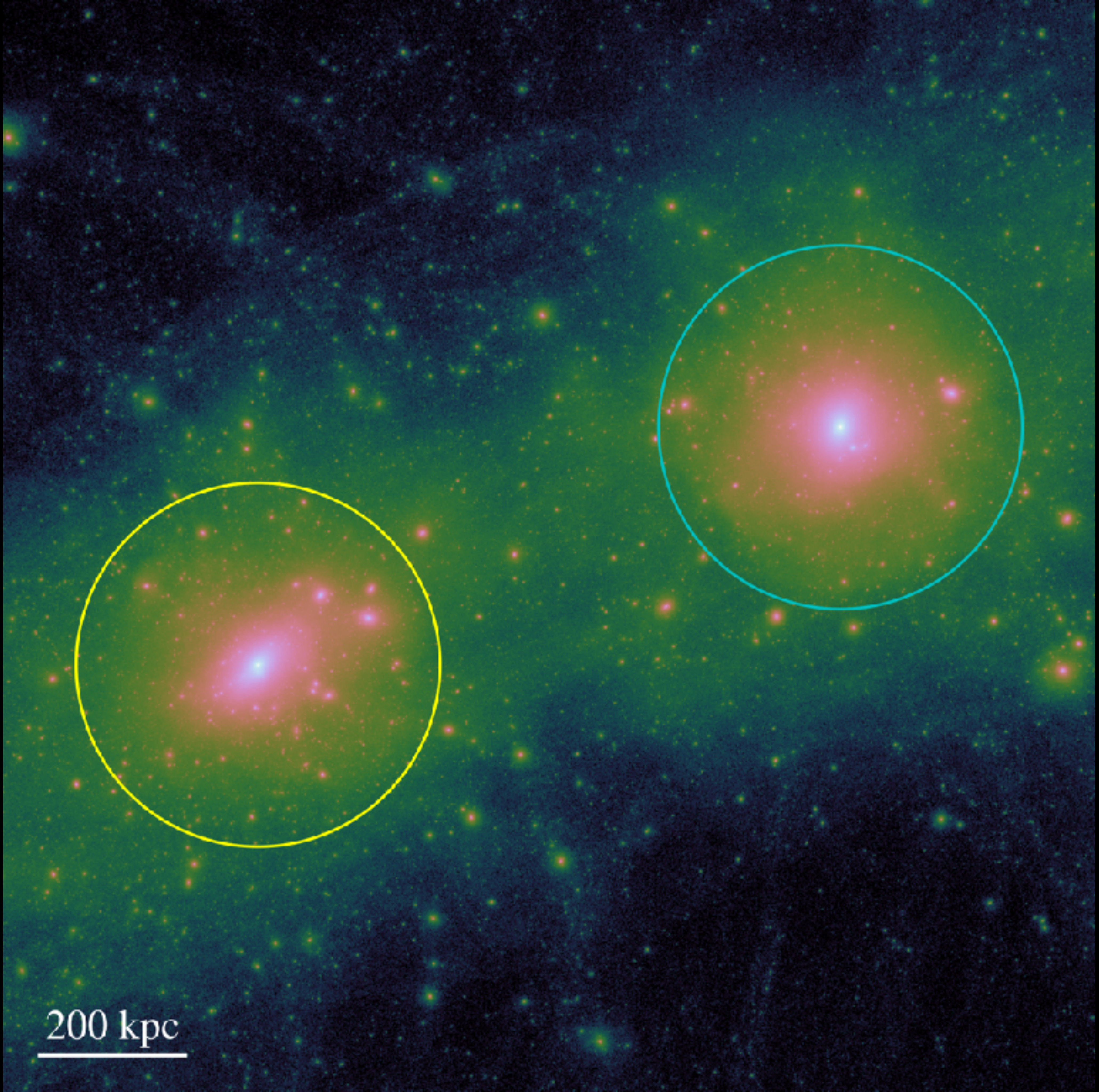
Preview: ELVIS on FIRE

$z \sim 0.2$ (now at $z < 0.1$)

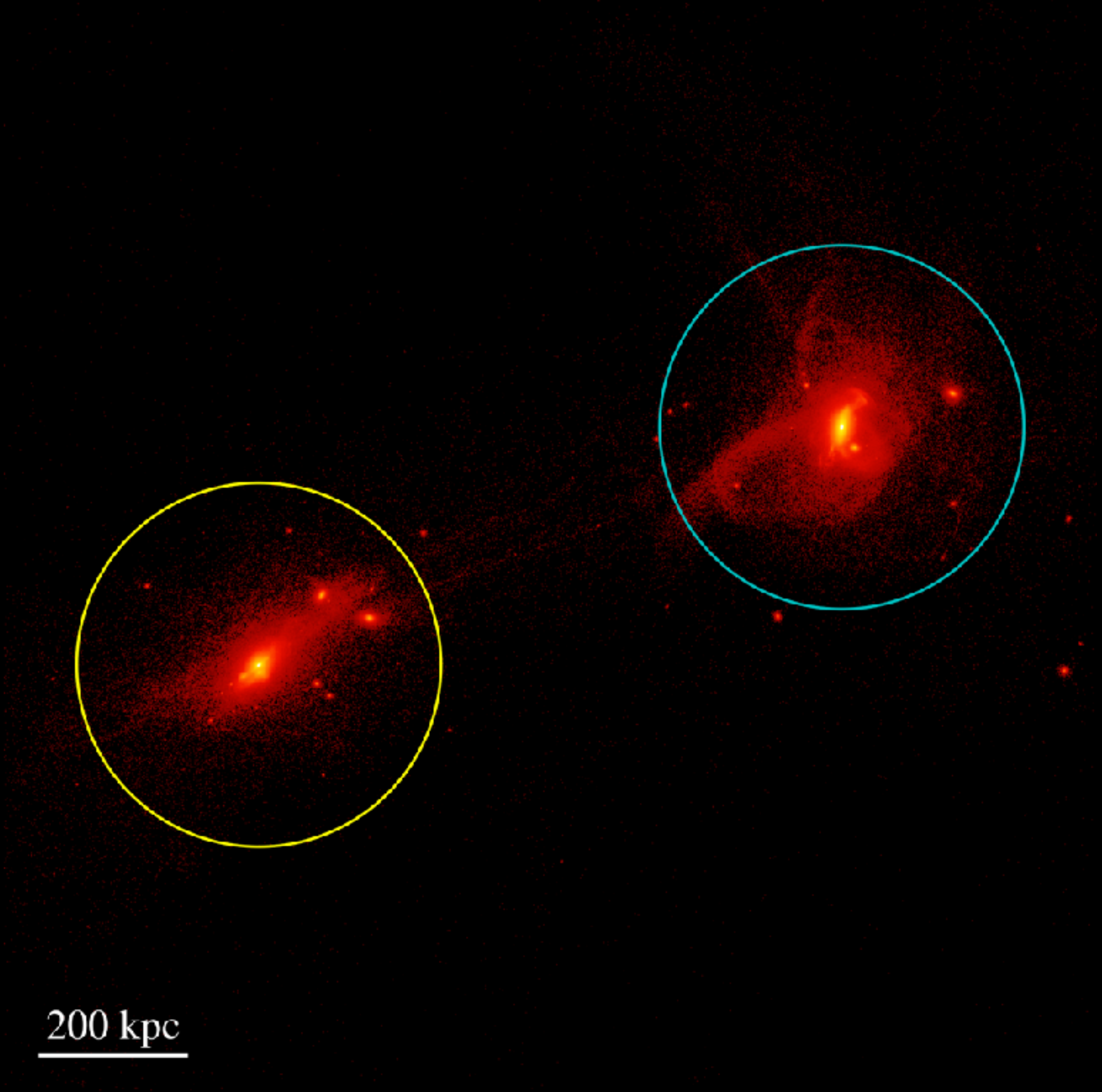


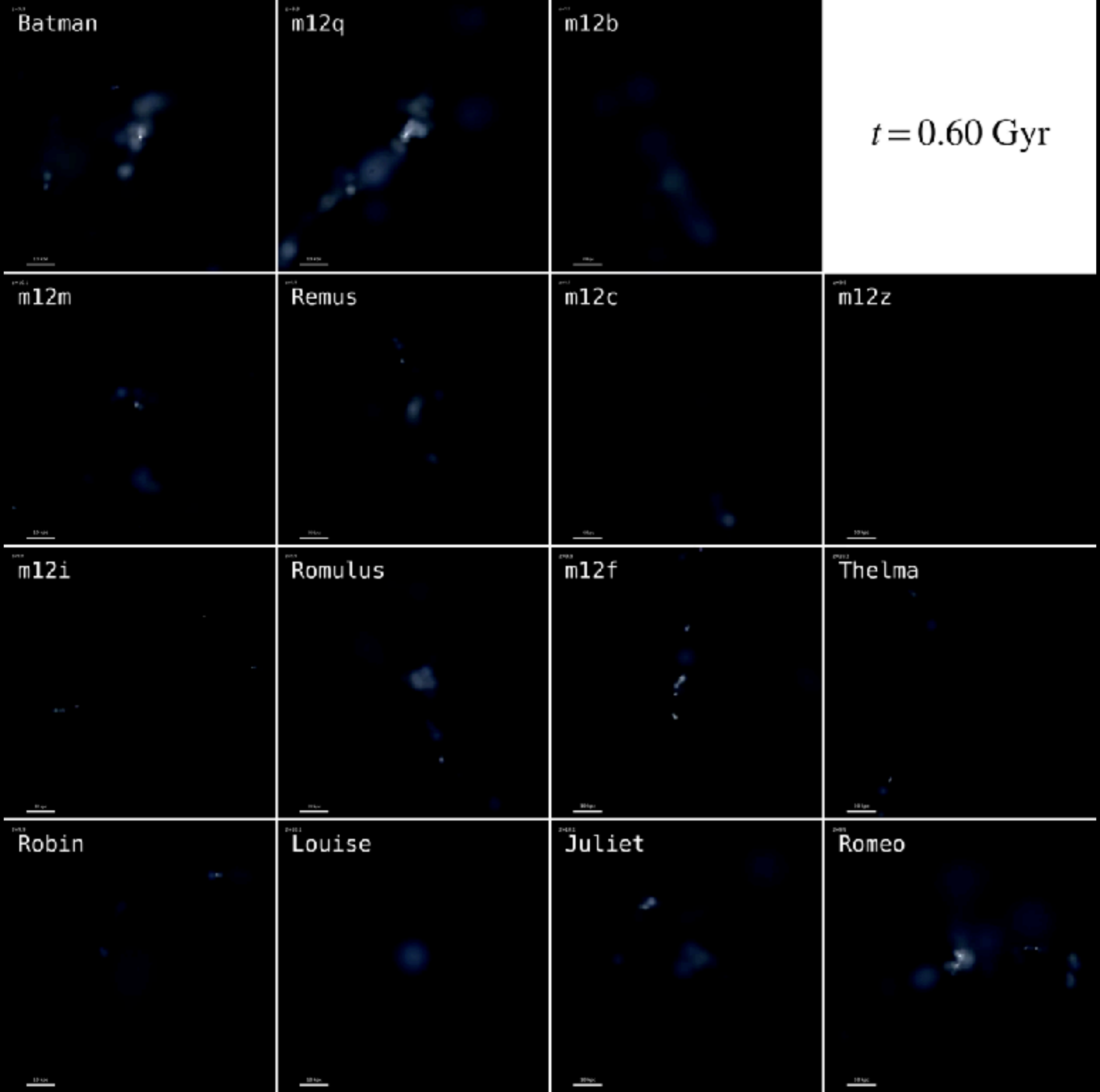
m_{gas} ~ 3500 M_{sun}

(will be) The highest resolution cosmological hydrodynamic simulation of a MW-mass galaxy ever completed



200 kpc


200 kpc


Batman
m12q
m12b
t = 0.60 Gyr
m12m
Remus
m12c
m12z
m12i
Romulus
m12f
Thelma
Robin
Louise
Juliet
Romeo

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