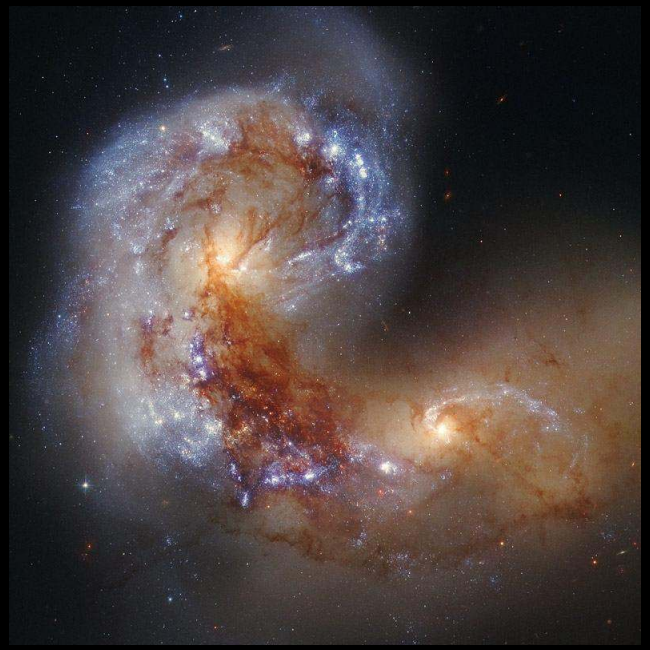
Formation and evolution of young massive clusters in simulated galaxy mergers

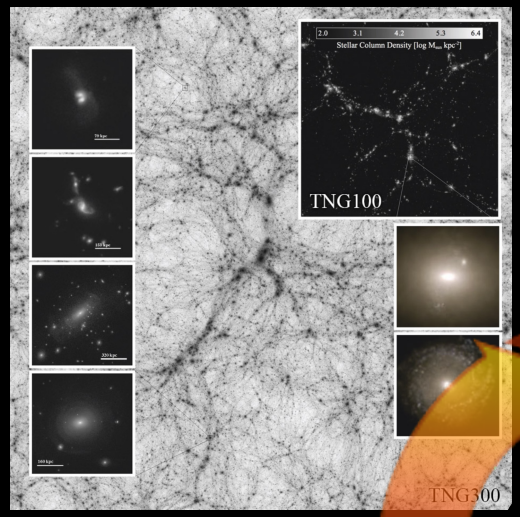


Hui Li (Hubble Fellow)

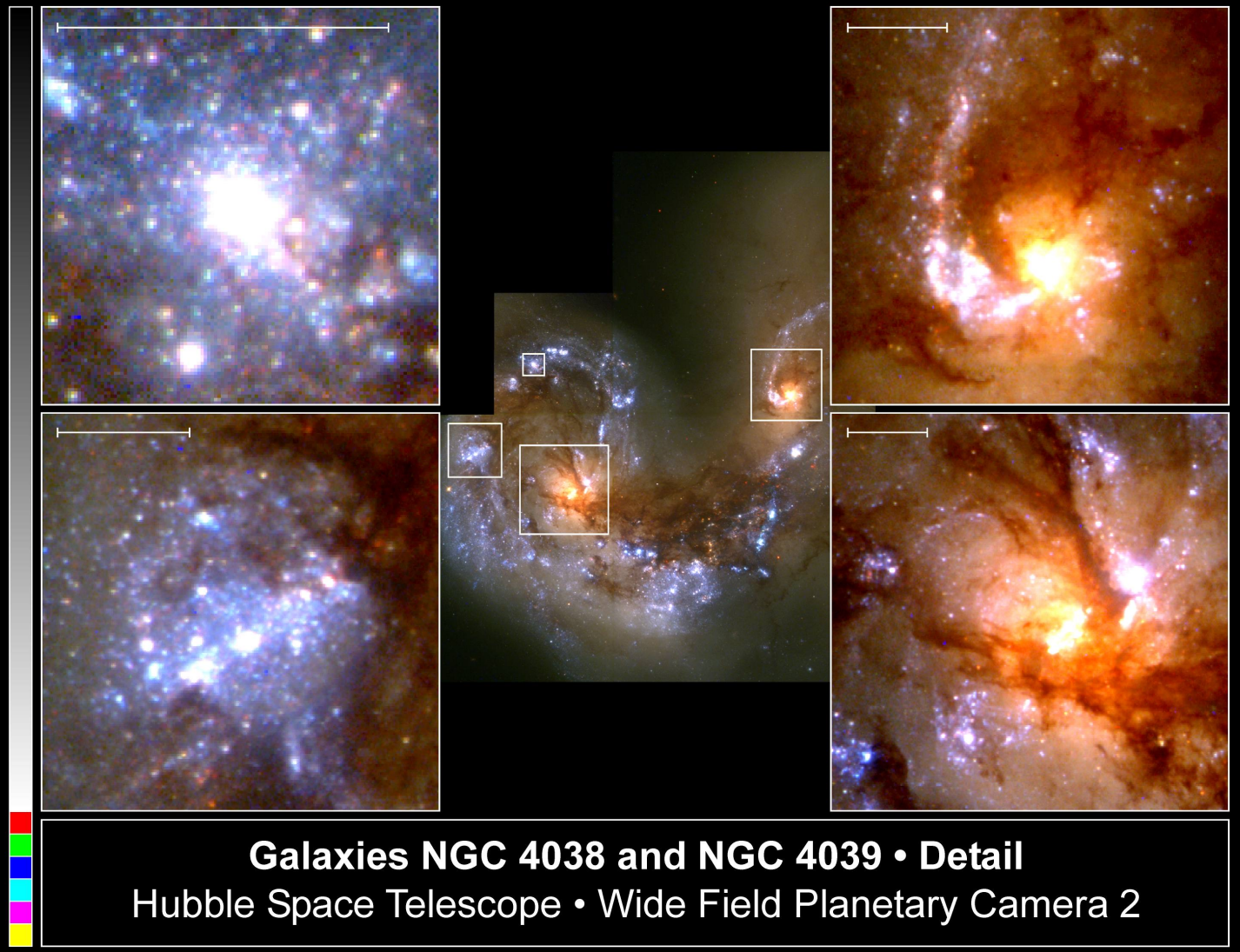
Columbia University

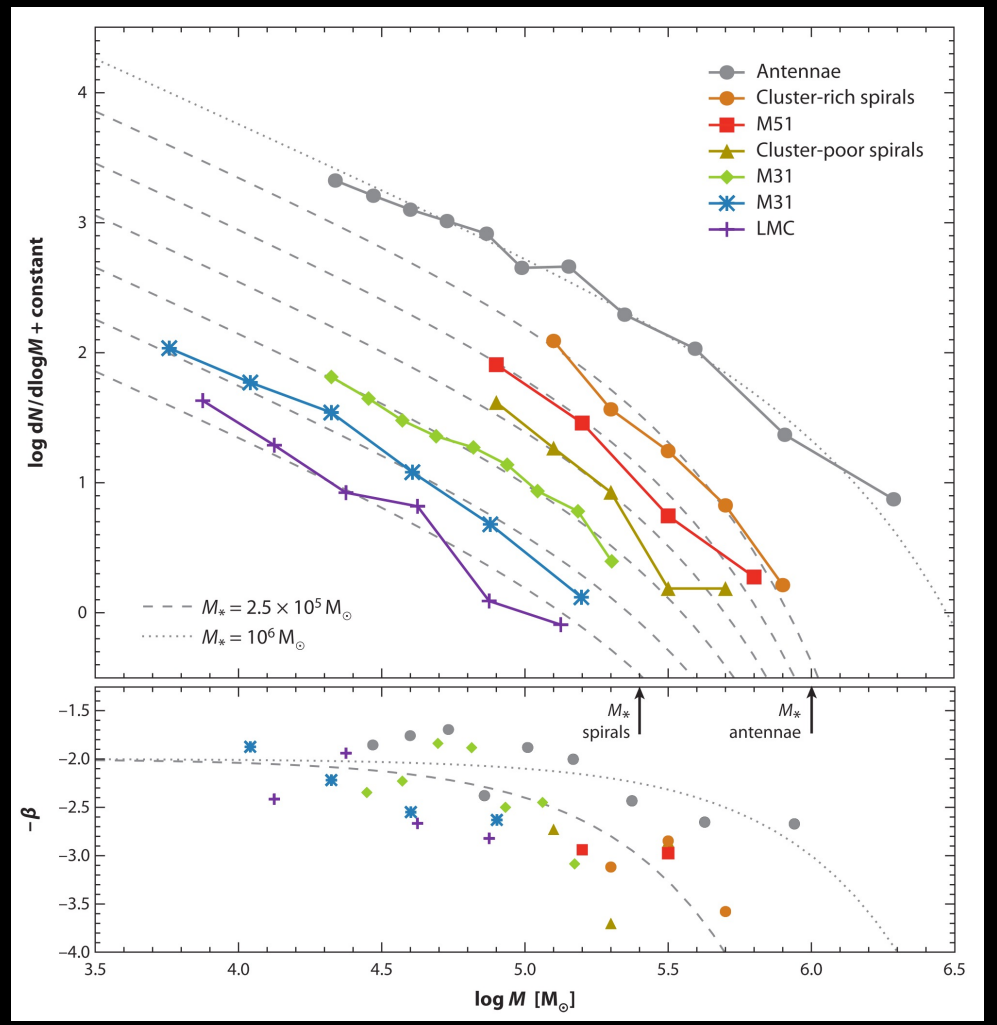
Key Collaborators: Mark Vogelsberger, Greg Bryan, Federico Marinacci, Laura Sales, Paul Torrey

NASA Hubble Fellowship Program


2.0 3.1 4.2 5.3 6.4
Stellar Column Density [log M$_{sun}$ kpc^{-2}]
TNG100
TNG300

Antennae galaxies as factory of young massive clusters (YMCs)

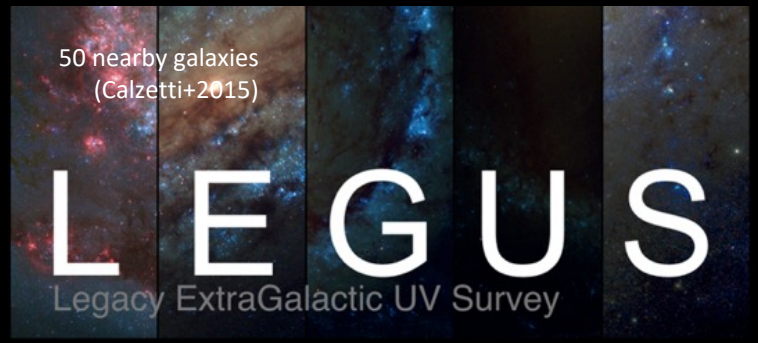




Portegies Zwart+2010

Linden et al. 2021

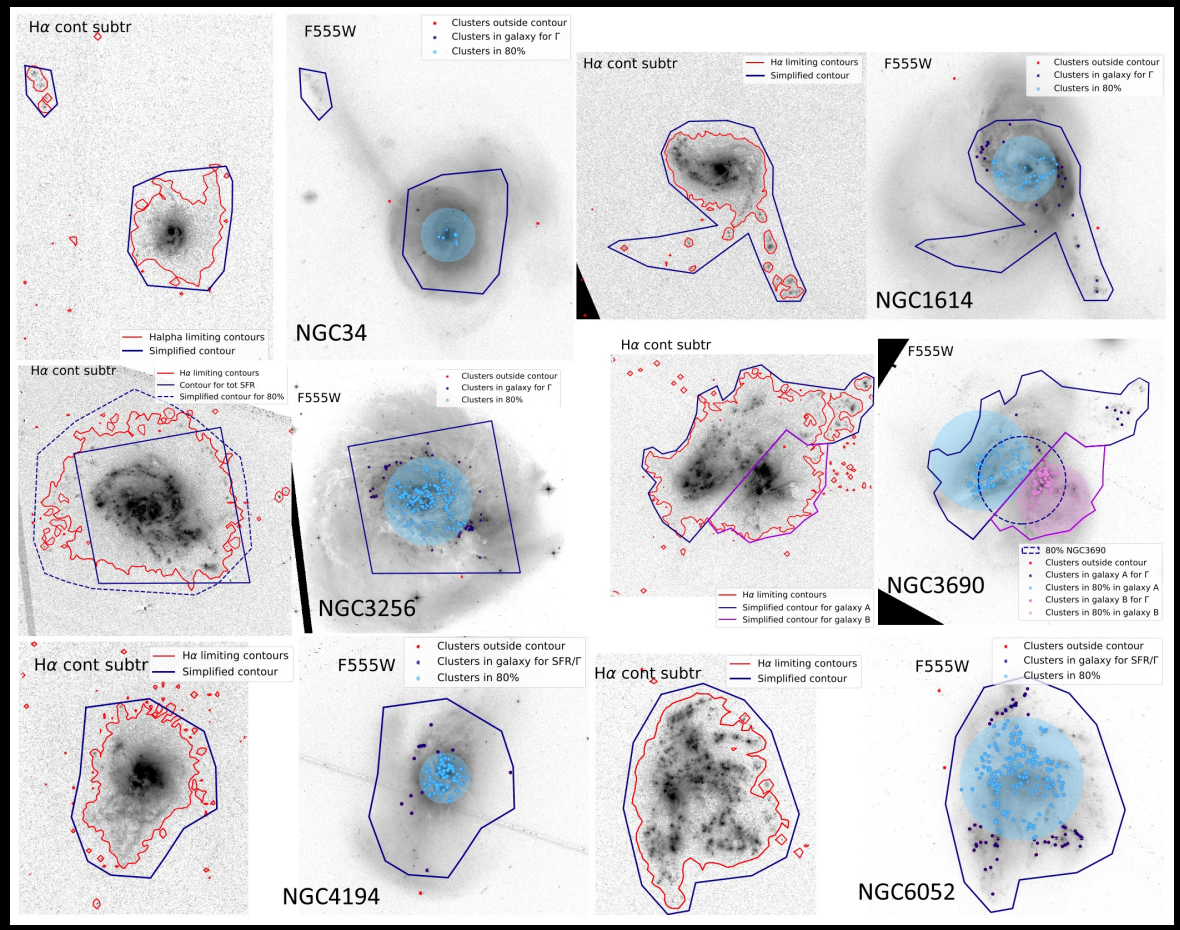
GOALS



PHANGS

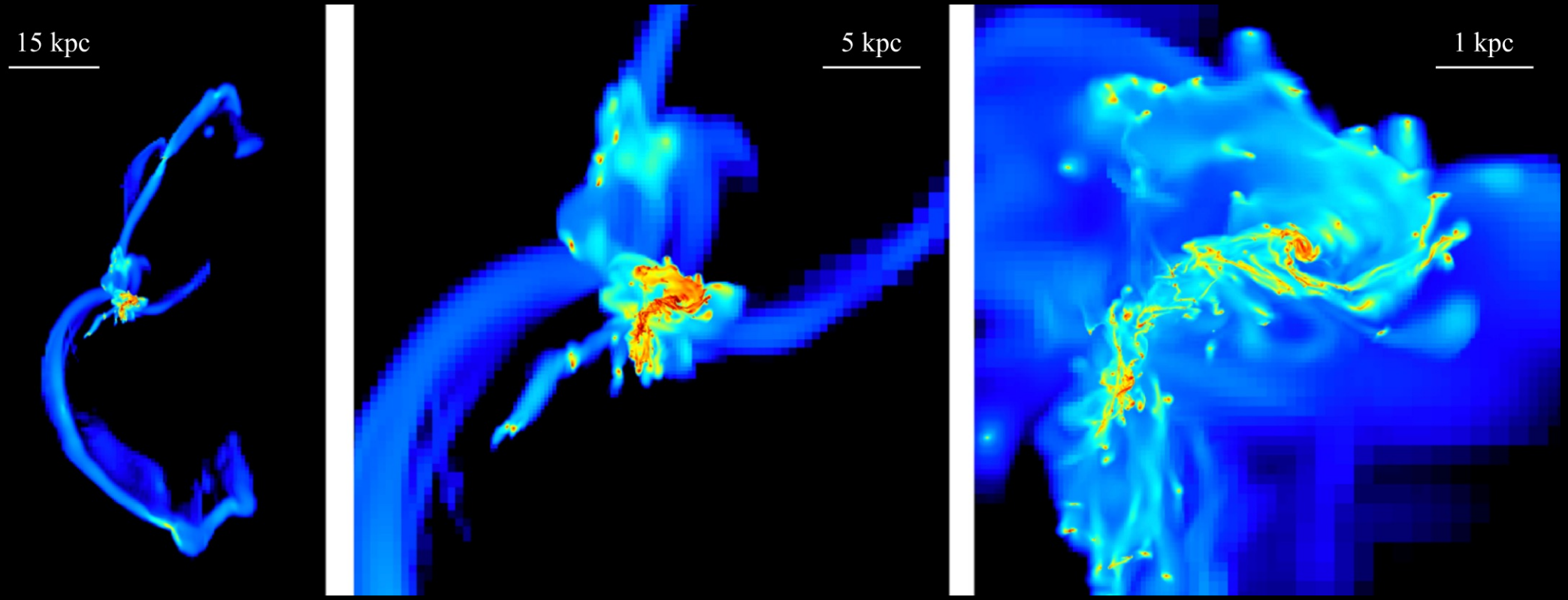
ALMA-PHANGS

HiPEEC survey



Adamo et al. 2020

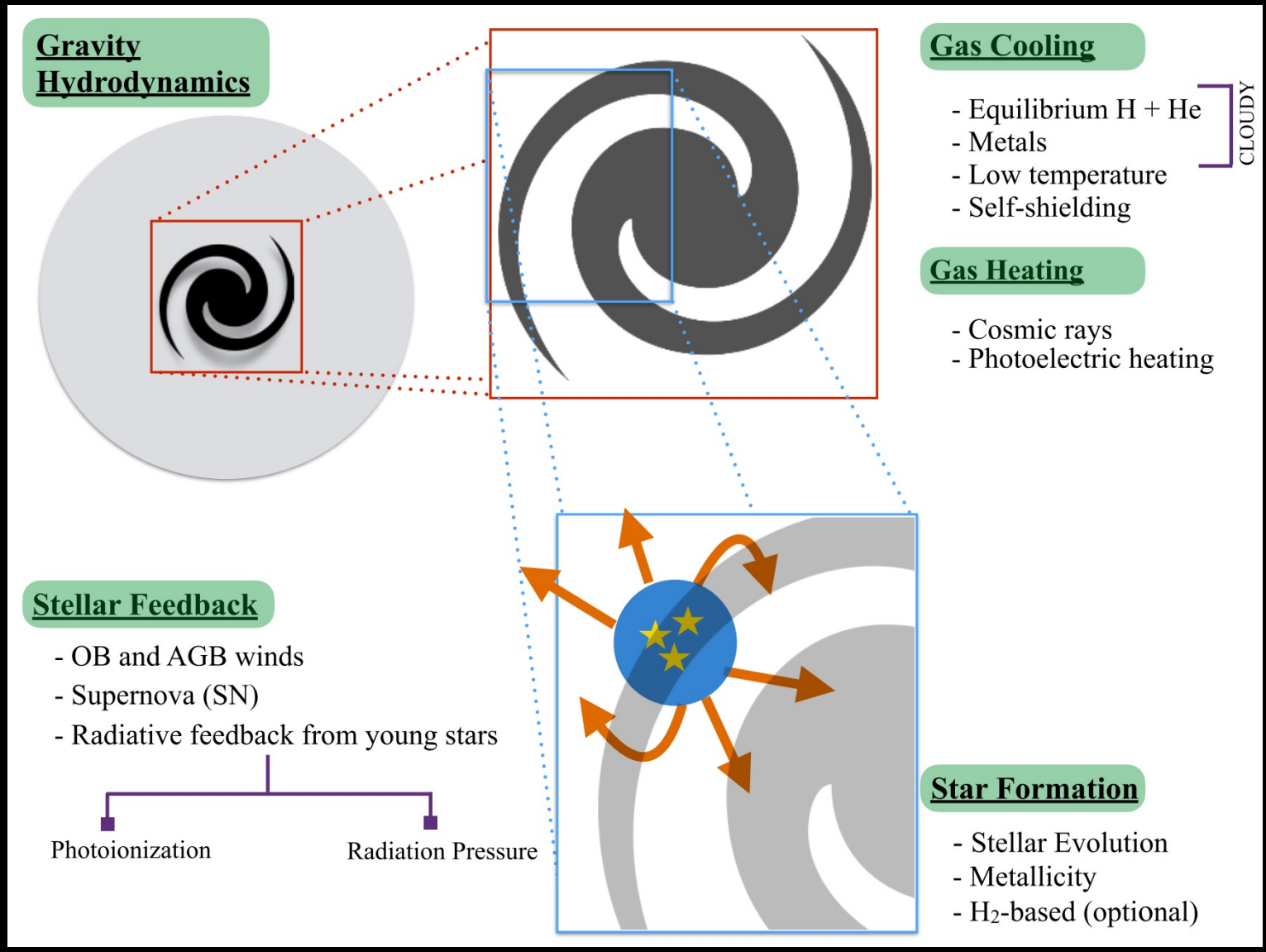
Merger simulations with resolved YMC populations



Renaud+15, see also Bournaud+08, Matsui+12, Powell+13, Lahen+20

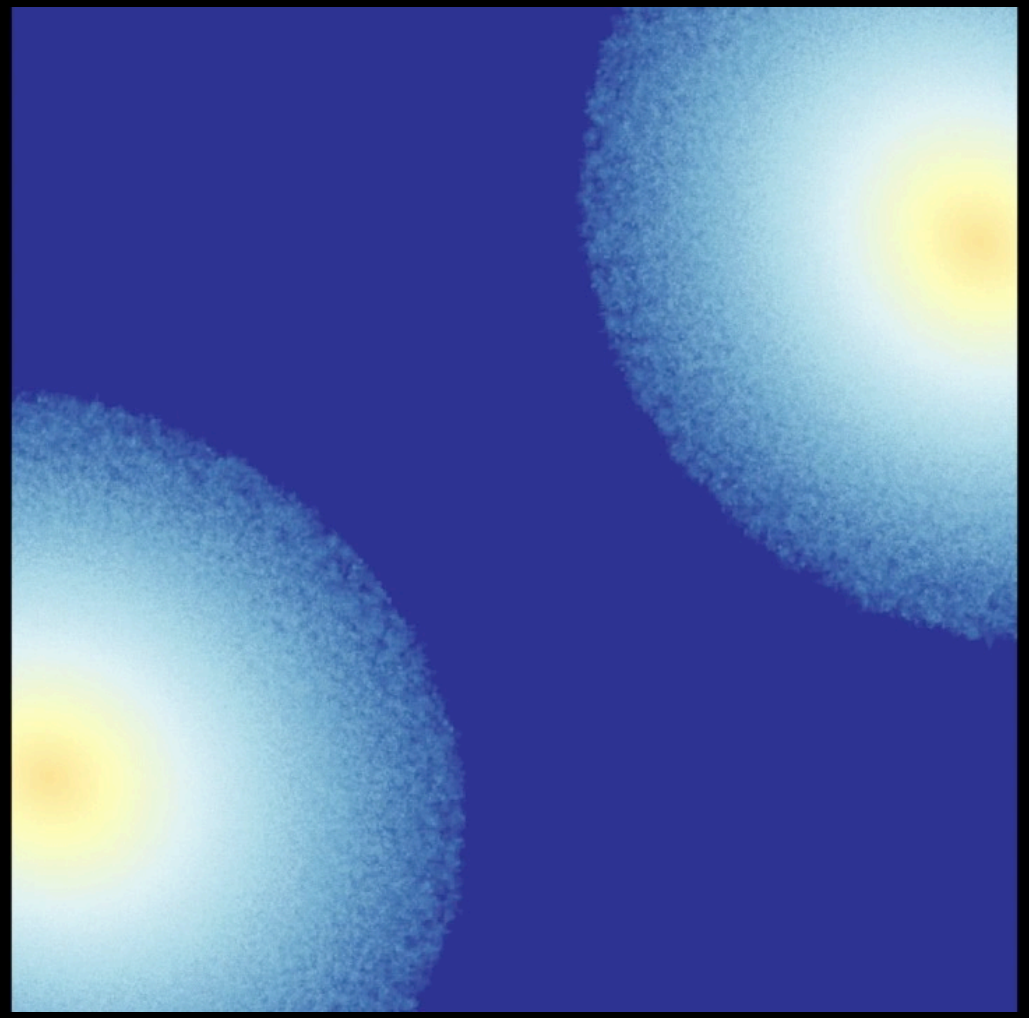
Stars and MUltiphase Gas in GaLaxiEs —— SMUGGLE

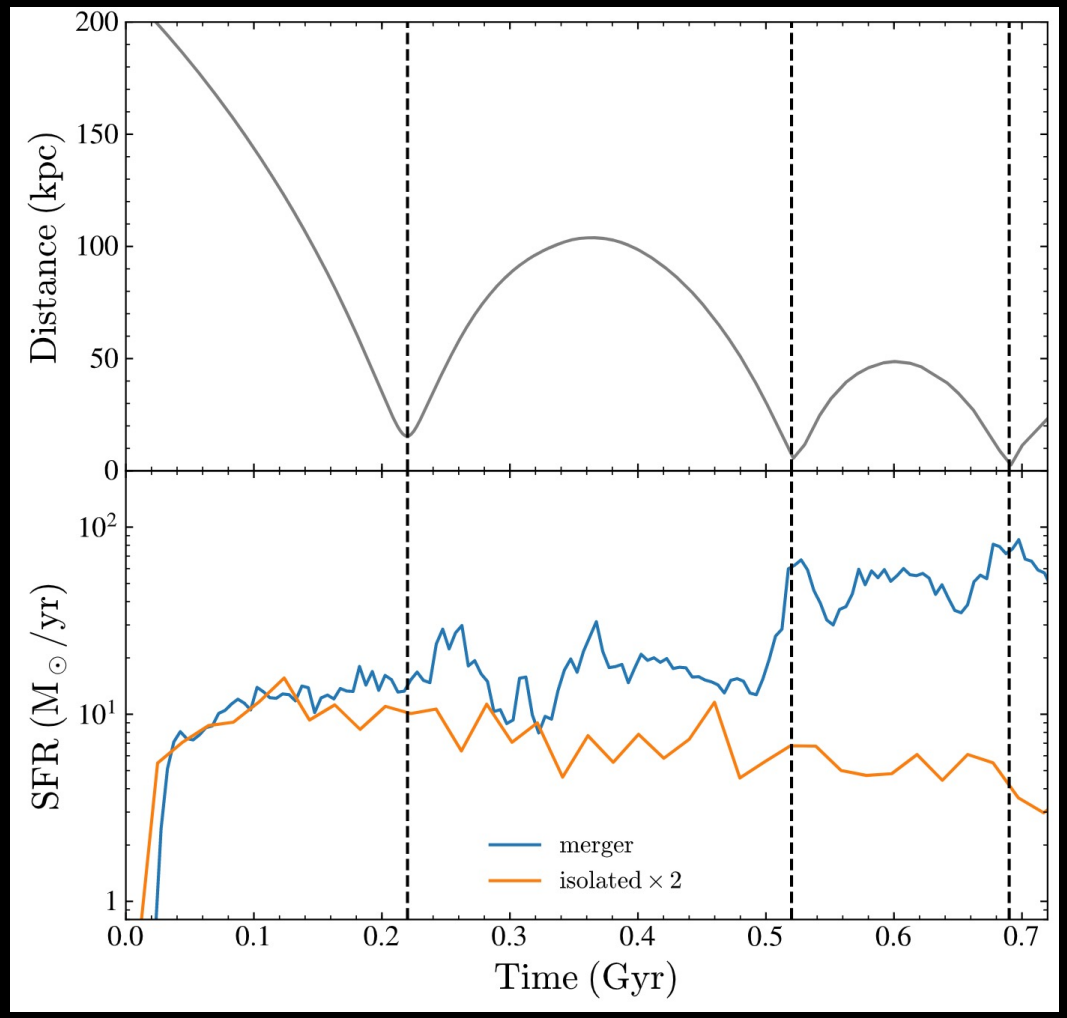
AREPO, a moving-mesh hydrodynamics with adaptive gravitational softening length



Marinacci et al. 2019

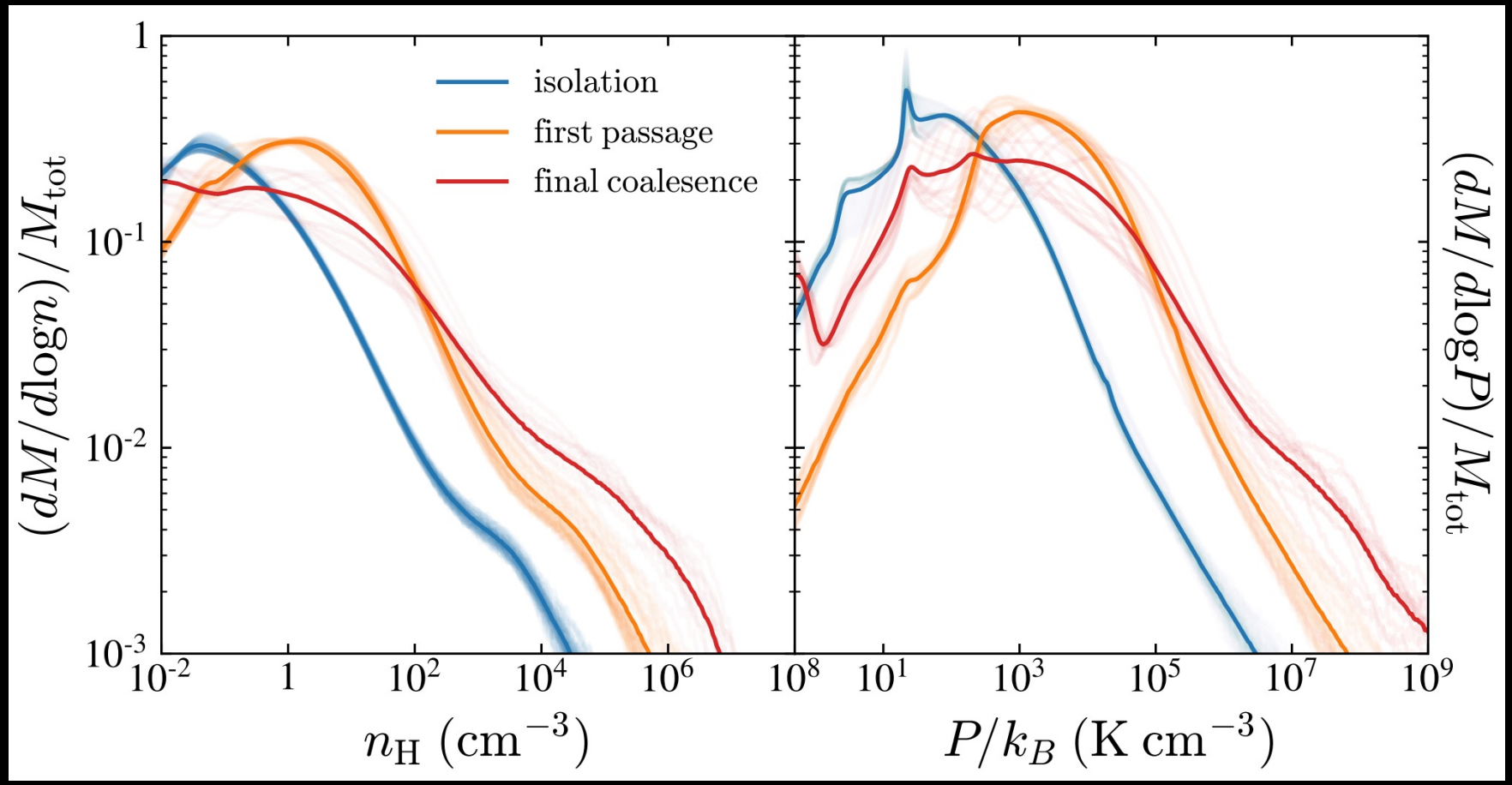
Star formation history during the whole merger sequence



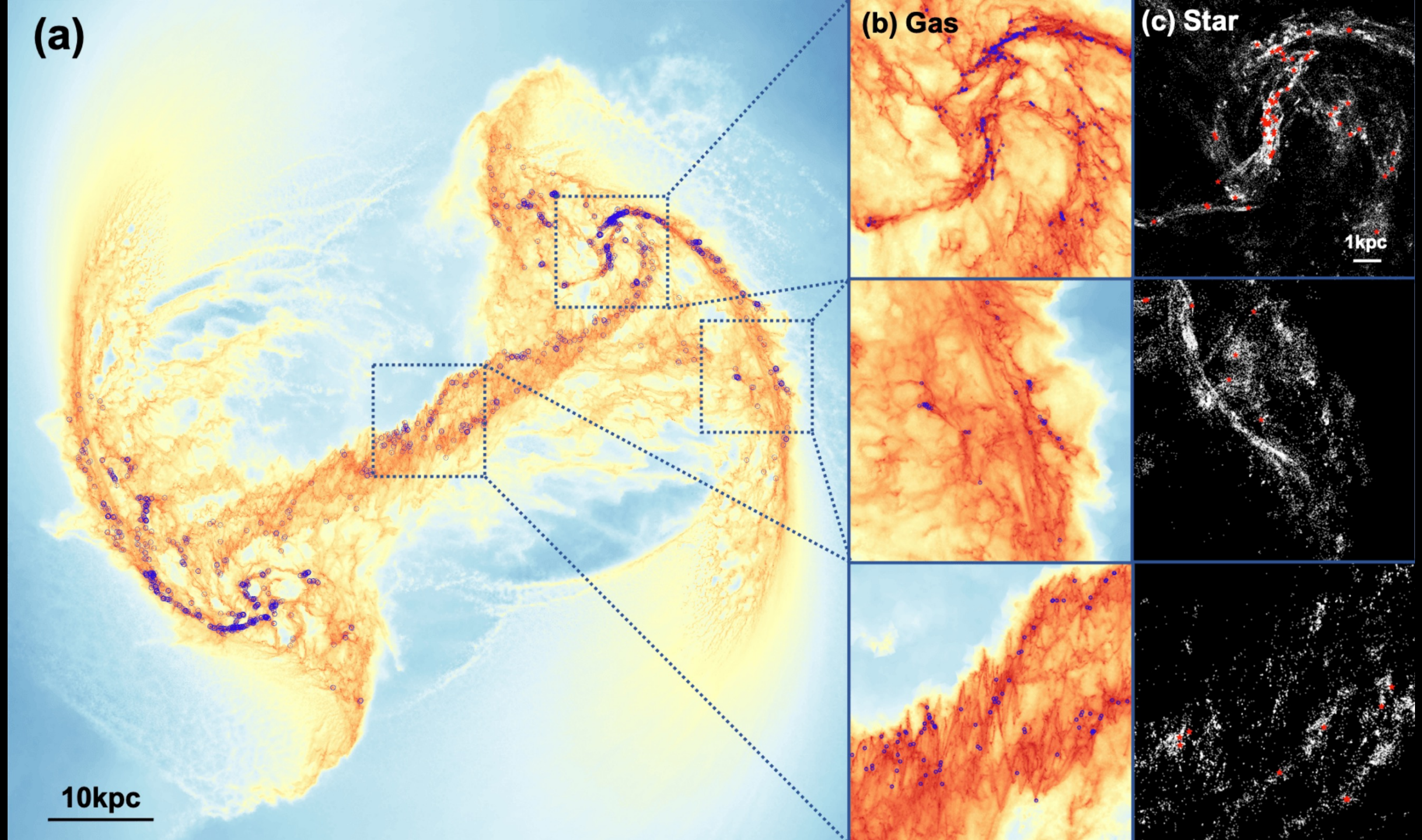


For the information of the isolated galaxy, see Li et al. 2020

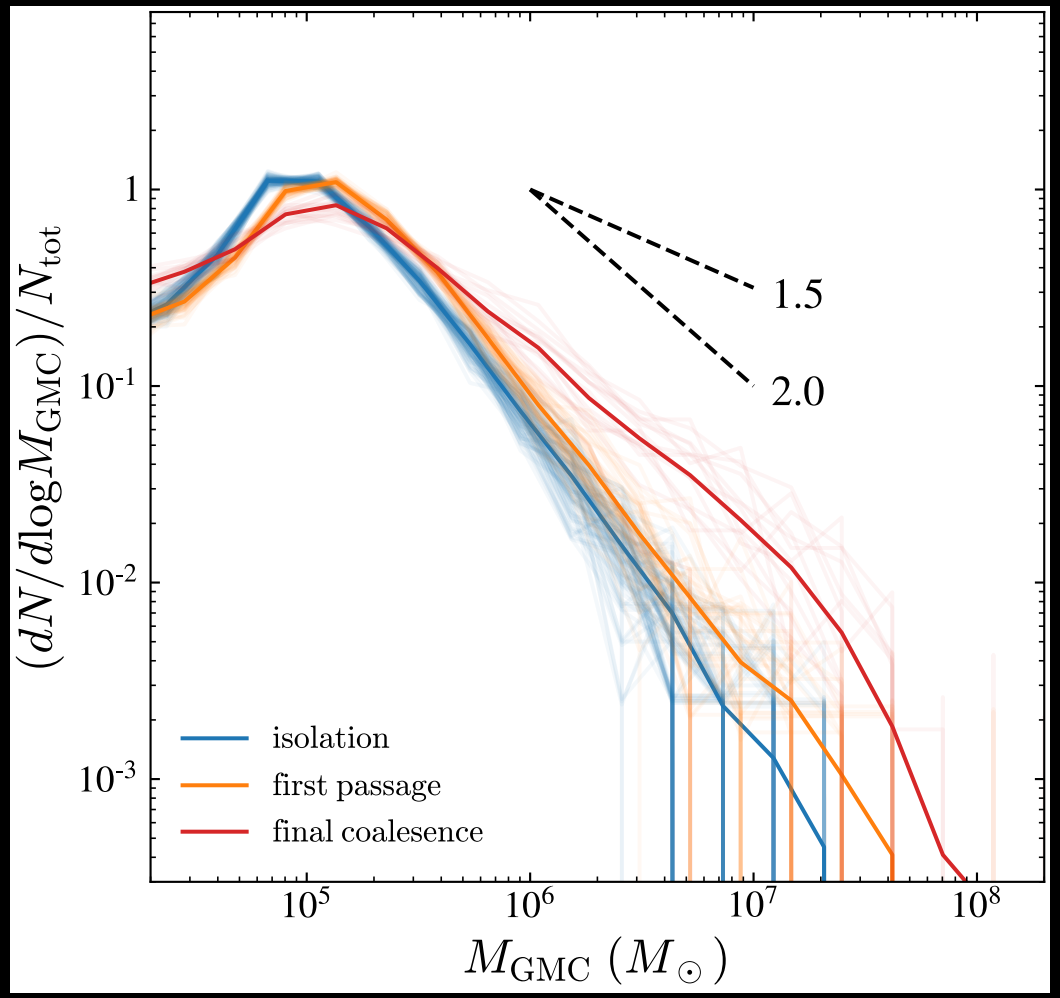
Dense, high pressure gas during mergers

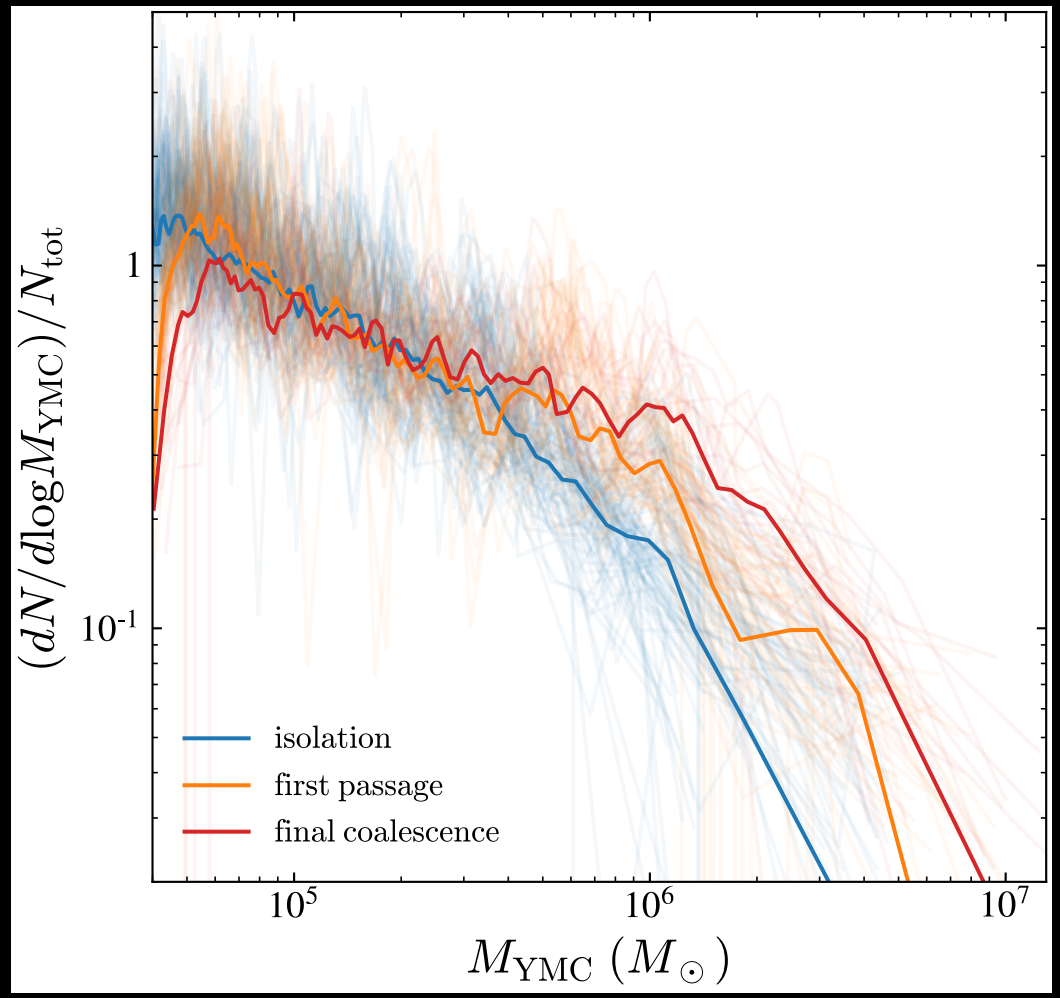


- After the first passage, compressive tides trigger the formation of dense, high pressure gas.
- After the final coalescence, the remaining gas loss its angular momentum and flow into the center of the merger remnants.
- The gas pressure can reach >1e7 K/cm3, several orders of magnitude higher than the mean ISM pressure in our Galaxy.


(a)
(b) Gas
(c) Star
1kpc
10kpc

Mass function of GMCs and YMCs: power-law shape



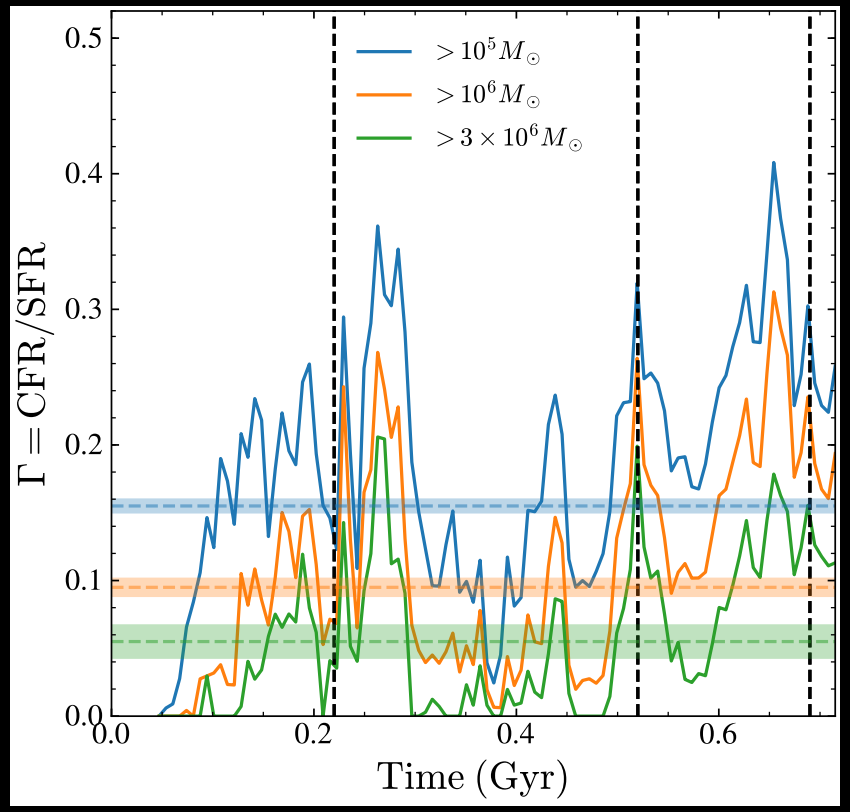


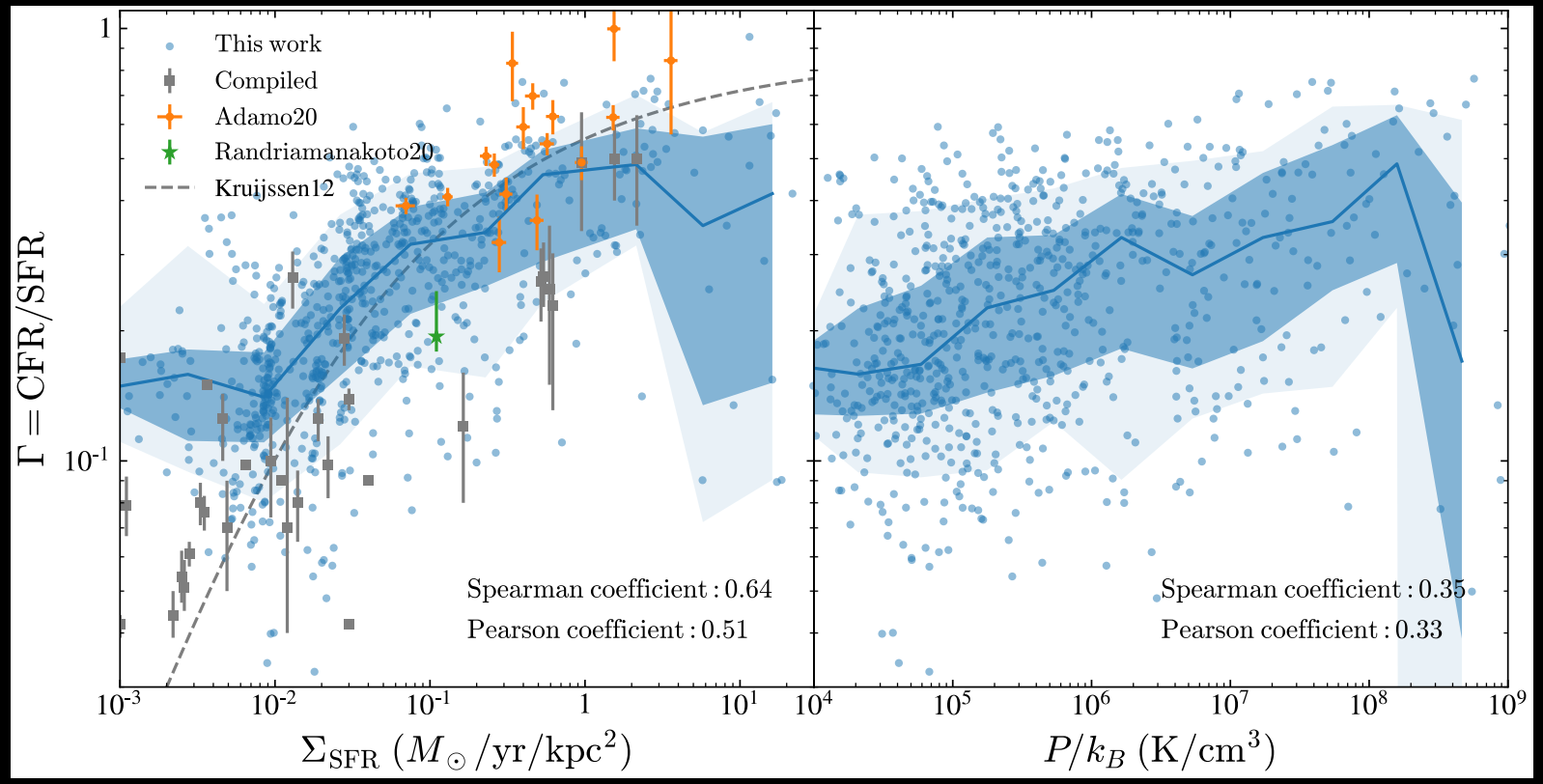
Both mass functions of GMCs and YMCs in different evolution stages show a power-law shape.
The slopes of the power-law is shallower during merger events.

See Sean Linden's Talk

Li et al. 2022 MNRAS in press

Cluster formation efficiency: cluster formation rate/star formation rate



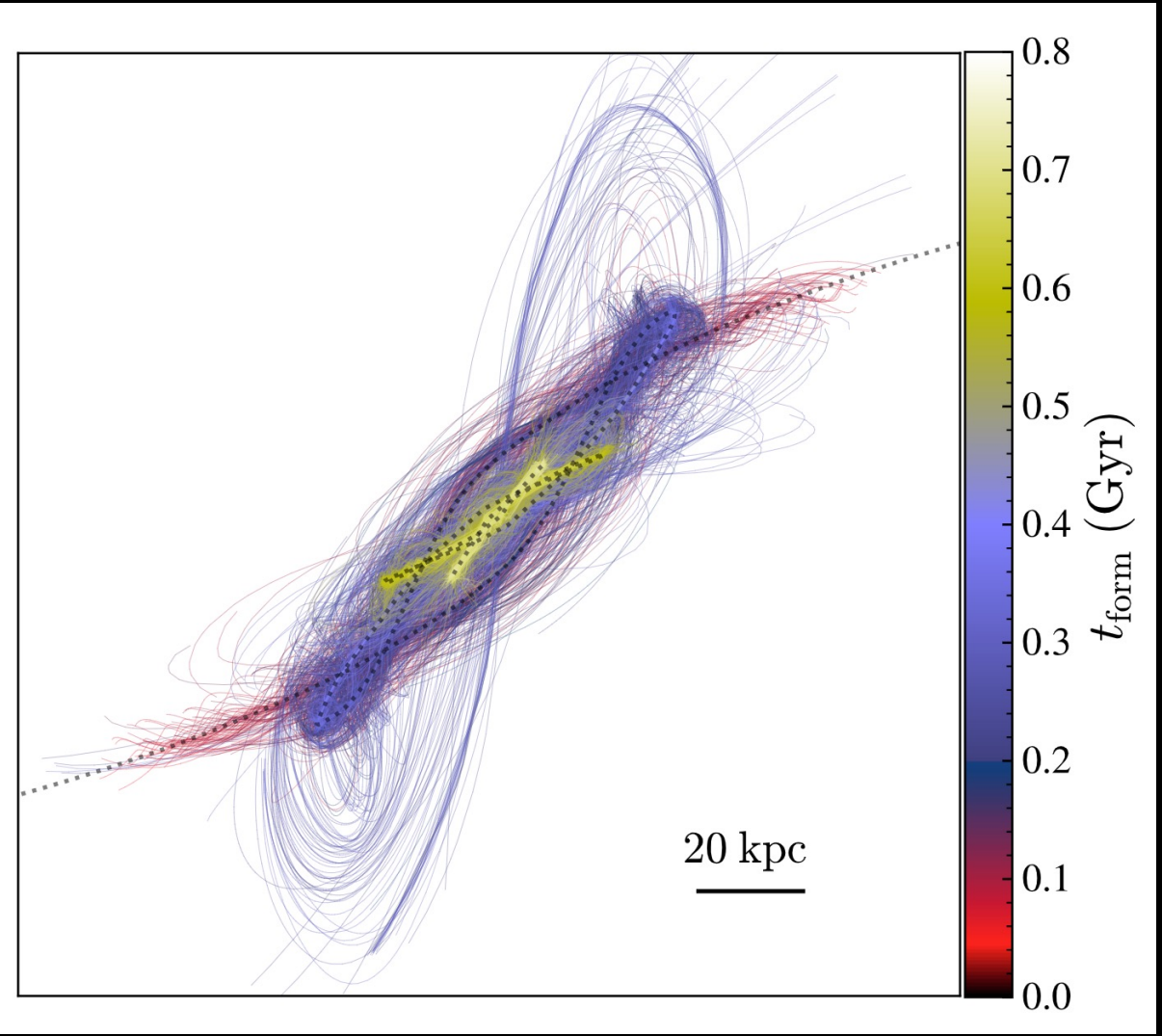


Cluster formation efficiency is largely enhanced after each merger events.

The efficiency depends positively on both the star formation rate surface density and gas pressure. This correlation suggests that cluster formation is an environment-dependent process

Li et al. 2022 MNRAS in press

Orbits of YMCs formed at different epochs during mergers



Track the orbits of individual YMCs during mergers

YMCs that are formed before the first passage tend to follow the orbits of the galaxies very closely and gradually sink into the galaxy centers.

YMCs formed during the first passage show signs of ejection. A large fraction has been thrown out to higher orbits.

Most of the YMCs formed during the final coalescence are concentrated at the very central region of the merger remnant.

Li et al. 2022 MNRAS in press

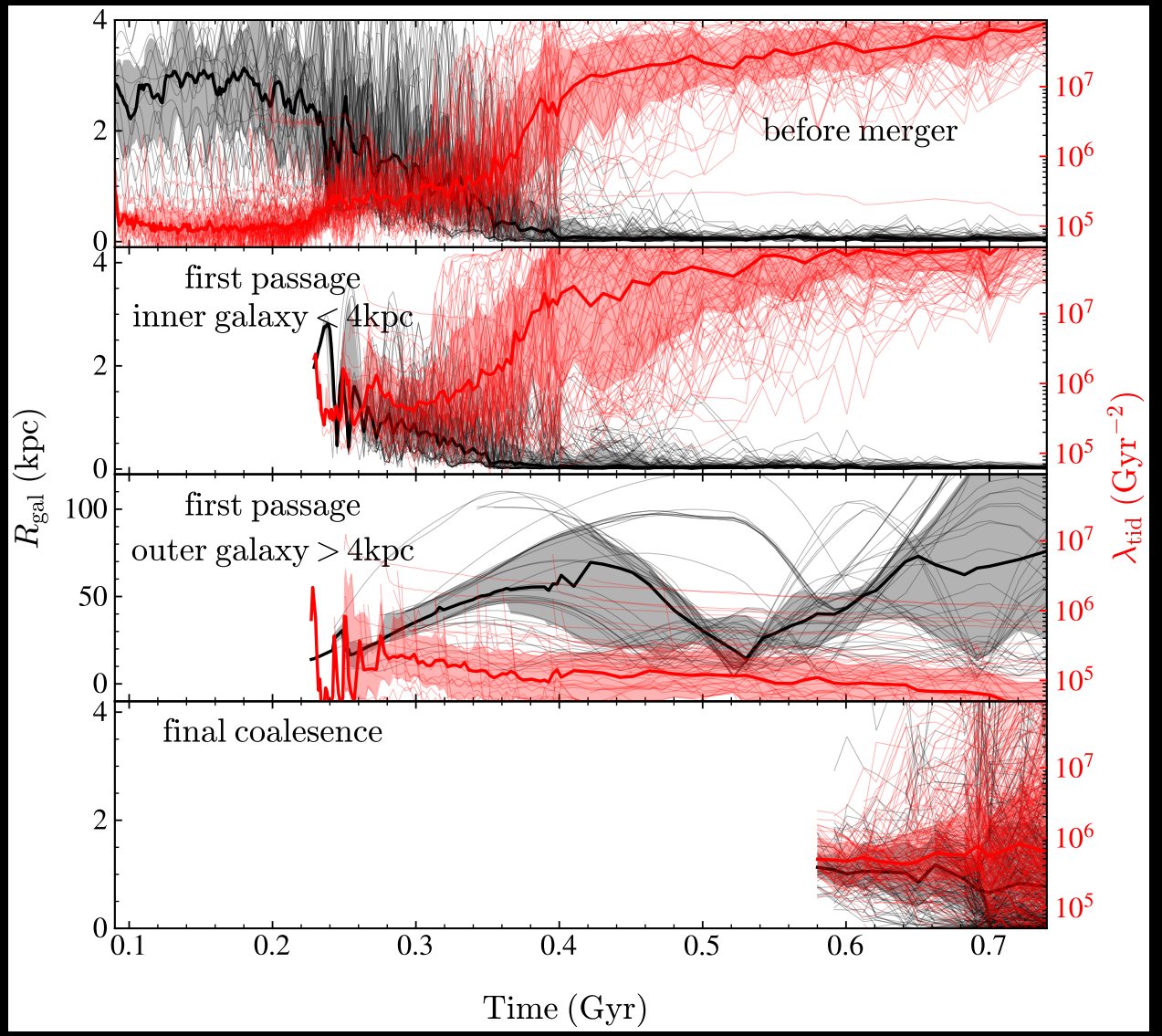
Orbital and tidal information: fates of YMCs during mergers

Use tidal tensors to trace the tidal field evolution during the entire merger process:

$$T_{ij}(x_0,t) \equiv -\frac{\partial^2 \Phi(\boldsymbol{x},t)}{\partial x_i \partial x_j}\bigg|_{\boldsymbol{x}=\boldsymbol{x}_0}$$

λ_{tid} is the maximum eigenvalue of the tidal tensor

- Most of the YMCs formed before the first passage sink into the center of the remnants in ~ 0.5 Gyr.
- YMCs formed during the final coalescence are located at the center of the remnants.
- YMCs formed in the outer disk/tidal tails during the first passage can escape to larger galacto-centric radii and survive.



Li et al. 2022 MNRAS in press

Summary

- The SFR of the simulated galaxy pair is enhanced in all three interactions.
- The mass functions of GMCs and YMCs are described by a power-law. The mass function has a shallower power-law slope during mergers and therefore extends to higher GMC/YMC masses.
- Cluster formation efficiency is boosted by a factor of a few during each merger events. The efficiency correlates strongly with star formation rate surface density and gas pressure, which demonstrates an environment-dependent cluster formation scenario.
- The majority of YMCs formed pre-merger sink into the center of the merger remnant in 0.5 Gyr due to dynamical friction and cannot survive. Only YMCs formed during the first passage can migrate to larger galactocentric radii, where the tidal disruption is minimal.
- A large fraction of YMCs formed during first passage can survive the tidal disruption across cosmic time and become promising candidates for globular clusters.