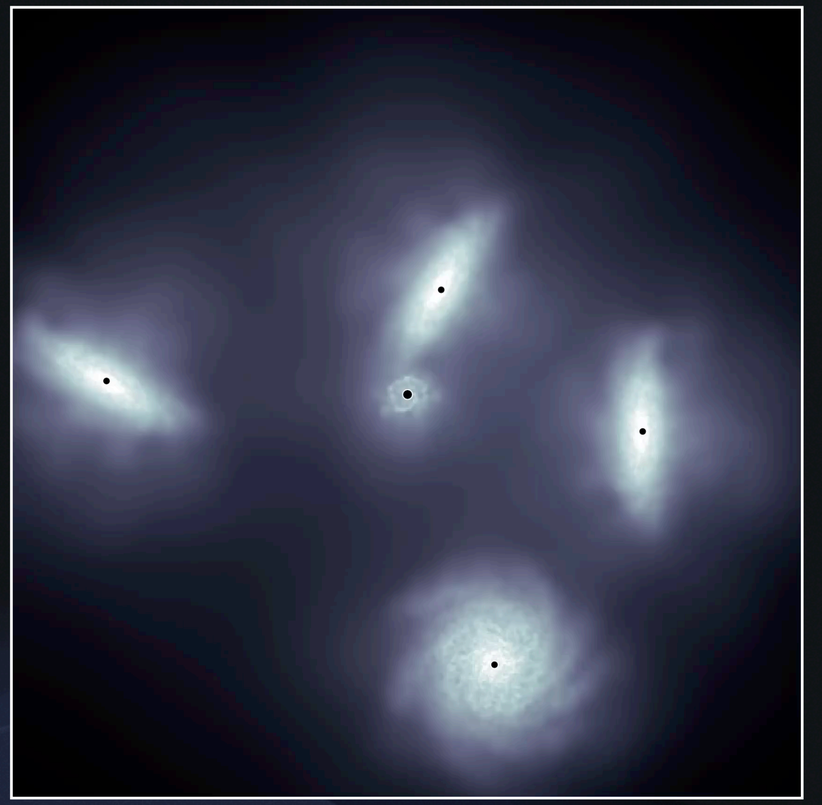
Simulating the evolution of massive high-redshift galaxies

into quiescent z ~ 2 red nuggets

Nordic-Baltic Astronomy Days 2026



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Outline

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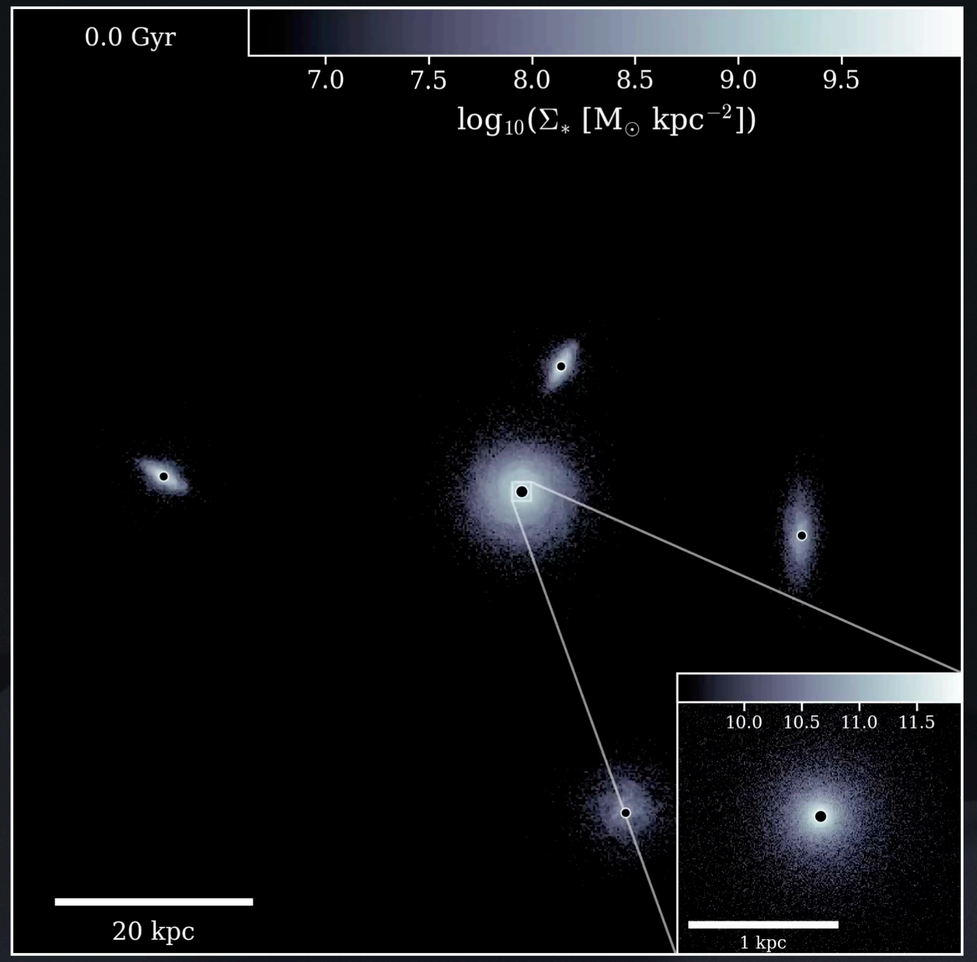
- **Background**
  - Massive quiescent galaxies at high redshift
  - Red nuggets
  - Black hole mergers
- **Simulations details**
  - Gadget-3 + Ketju
  - Merger histories
- **Results**



Merger between a massive quiescent galaxy + 4 satellite galaxies at z = 5

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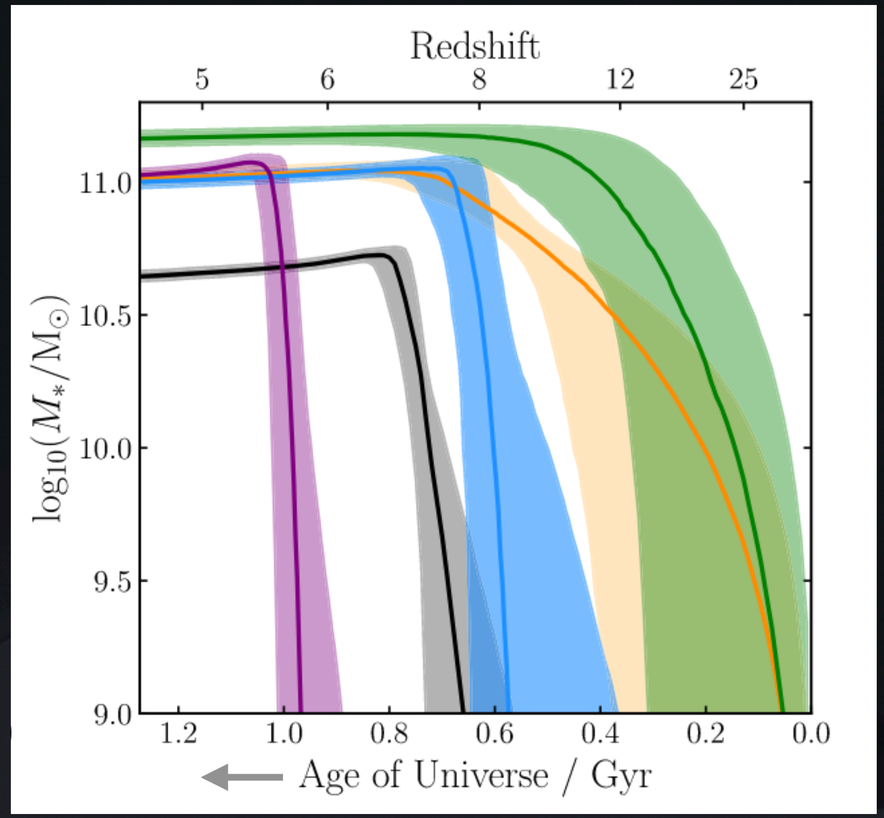
Background

Background

Quiescent galaxies

- Massive quiescent galaxies (MQGs) at z ~ 5
  - Observed number density higher with JWST
  - $M_{star} > 10^{10}$ M_{Sun}, extremely dense, formed fast
- Red nuggets at z ~ 2
  - r_{eff} ~ 1 kpc
  - Evolve into massive ellipticals → disappear by z = 0



Stellar mass evolution of observed MQGs based on star formation history [Carnall+24]

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Background

Supermassive black hole mergers

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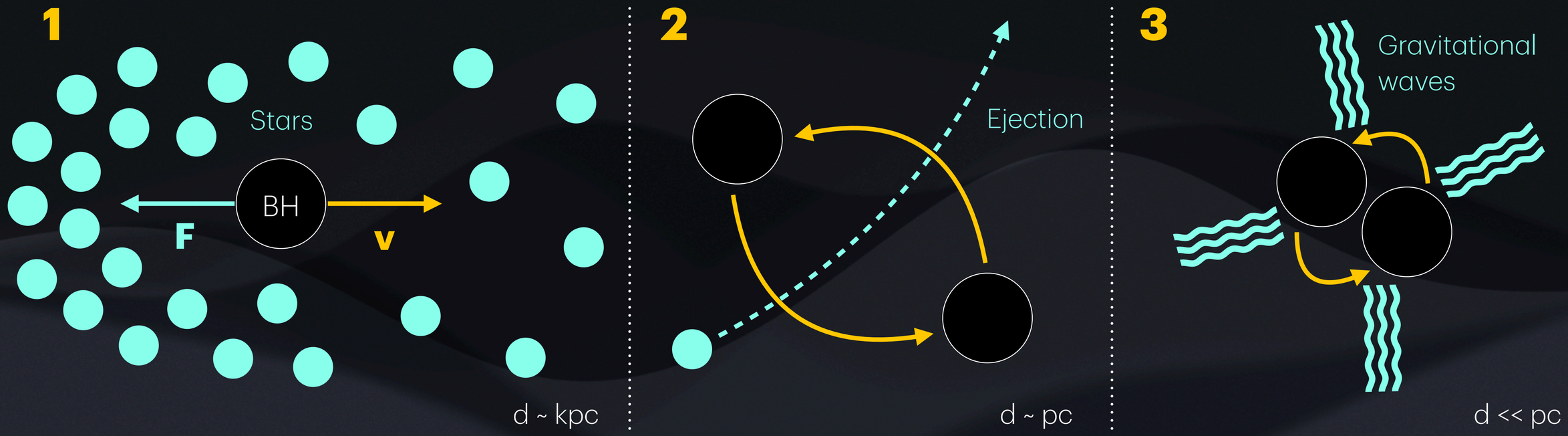
- Galaxies merge → central black holes merge
  - In three phases:



Simulation details

Aim

How does a MQG evolve from z = 5 to z = 2 via different merger histories?

Simulation details

Merger histories

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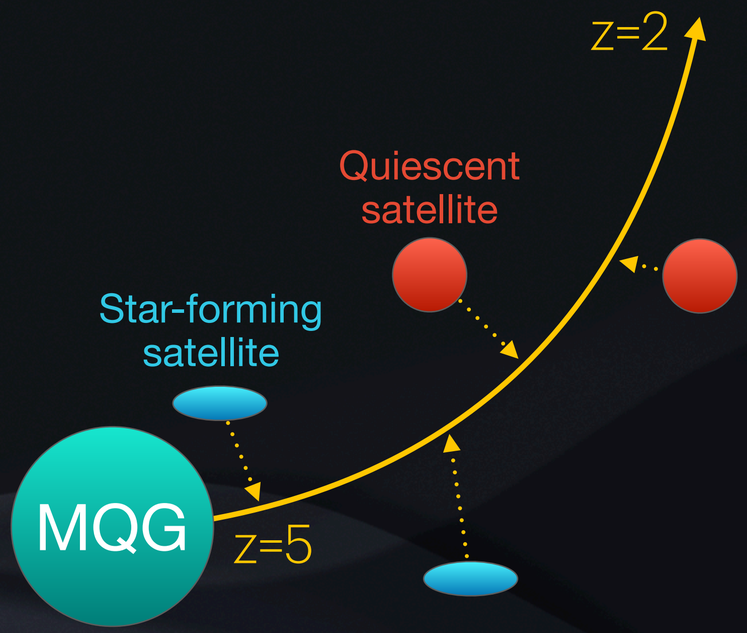
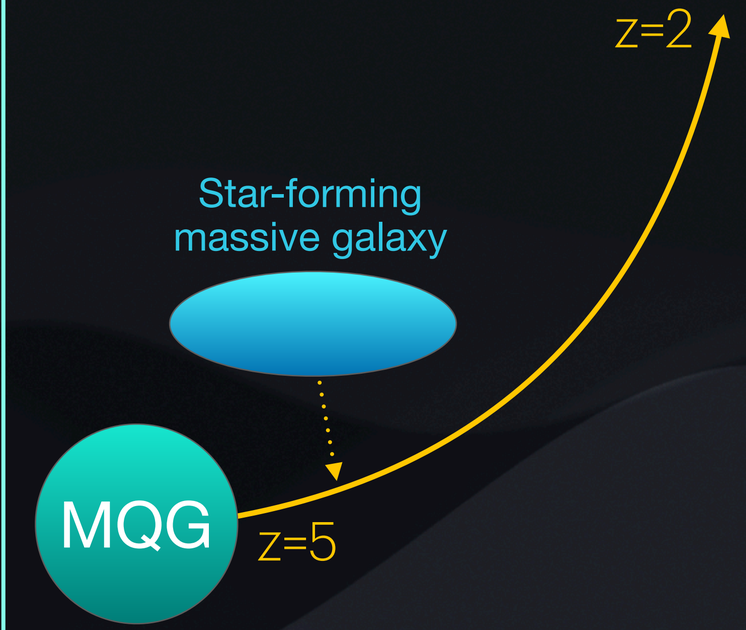
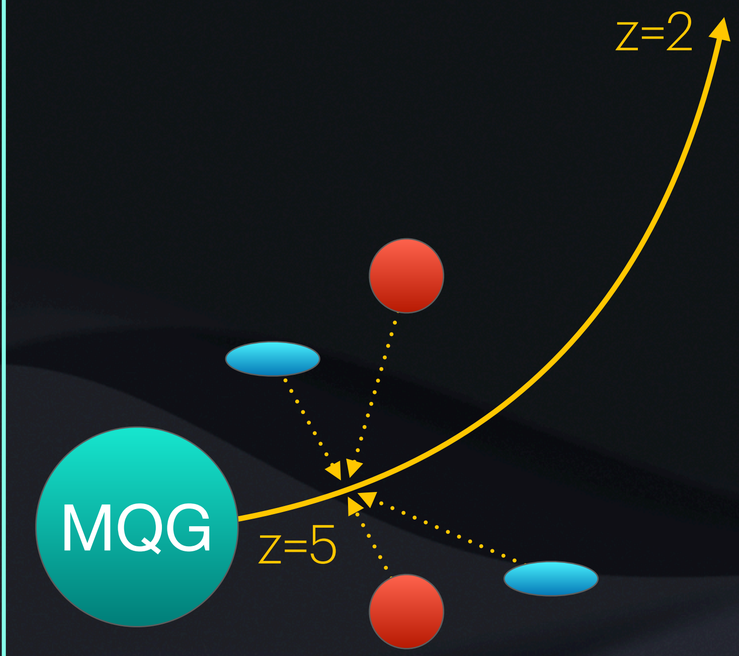
Sequences of 4 minor mergers



Individual major mergers



Multiple-satellite mergers



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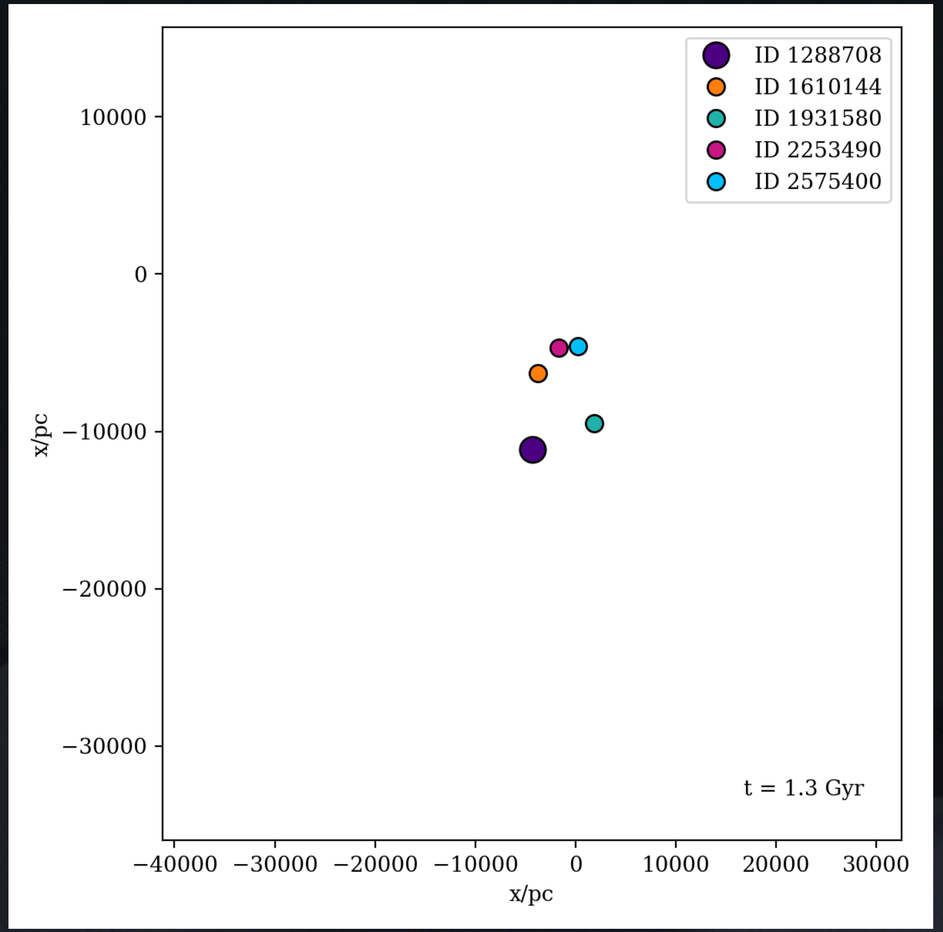
Simulation details

Numerical code

- Gadget-3 for large scales
  - Global dynamics, AGN feedback, star formation, gas cooling, stellar feedback...
- Ketju* around supermassive black holes
  - Non-softened dynamics between BHs and stars
  - BH mergers accurately resolved



BH trajectories in a merger between a MQG + 4 satellite galaxies

* publicly available here!

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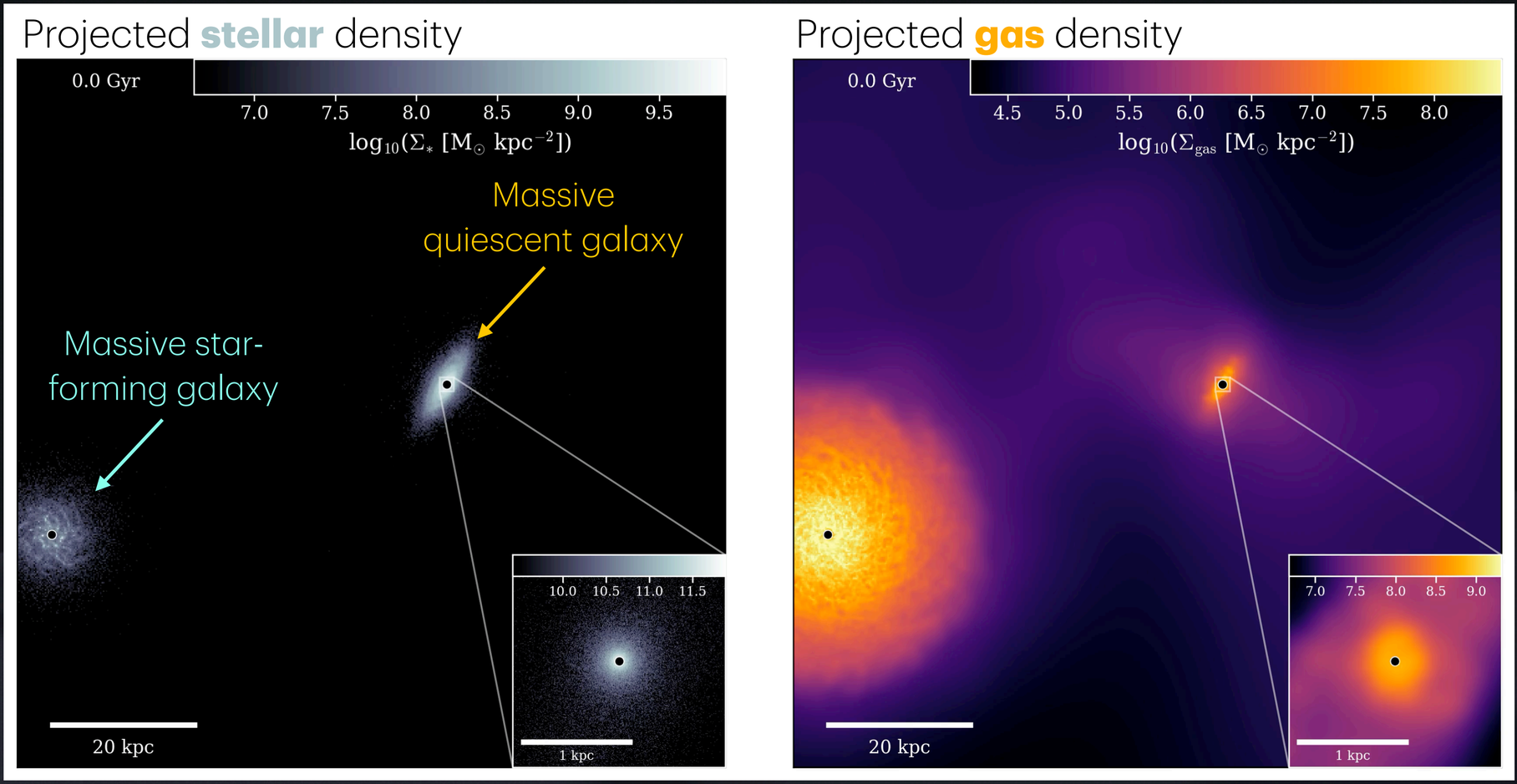
Simulation details

Example simulation: gas-rich major merger at z = 5

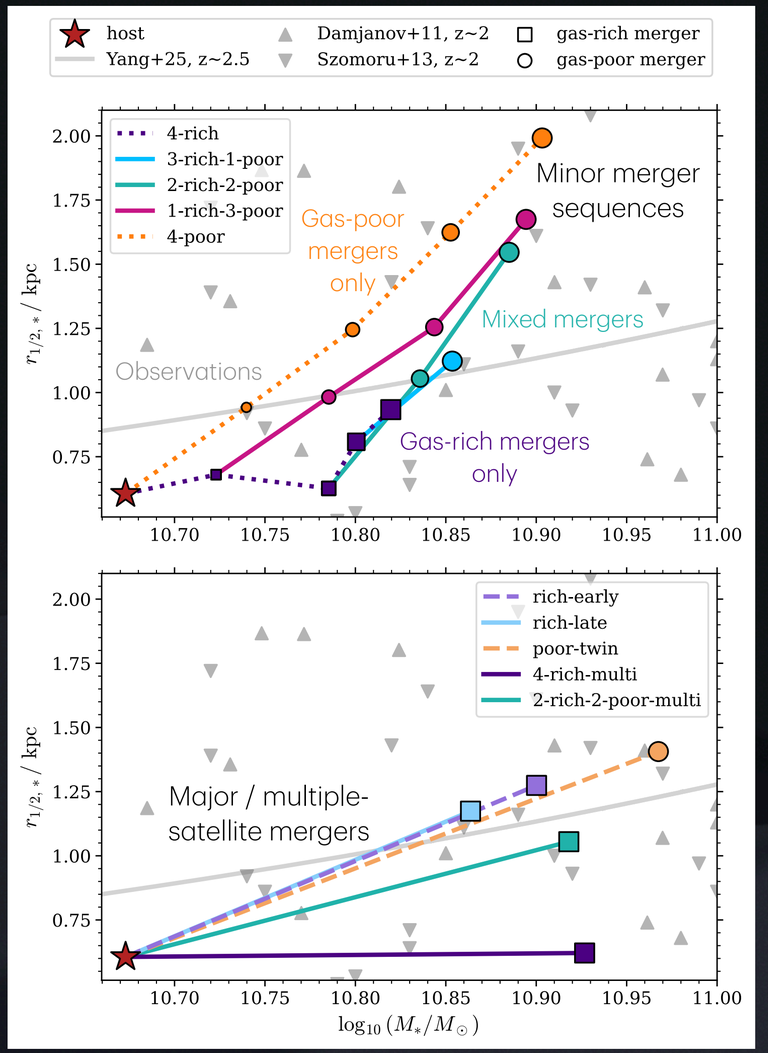


Results

Results

Size evolution

- Gas-rich mergers → weaker size growth
  - Central star formation suppresses growth
- Gas-poor mergers: stronger size growth in minor mergers
  - Stripped satellite stars deposited at large radii
- Gas-rich (minor) mergers needed to maintain $r_{1/2}$ ~ 1 kpc



Mattero+, in prep.

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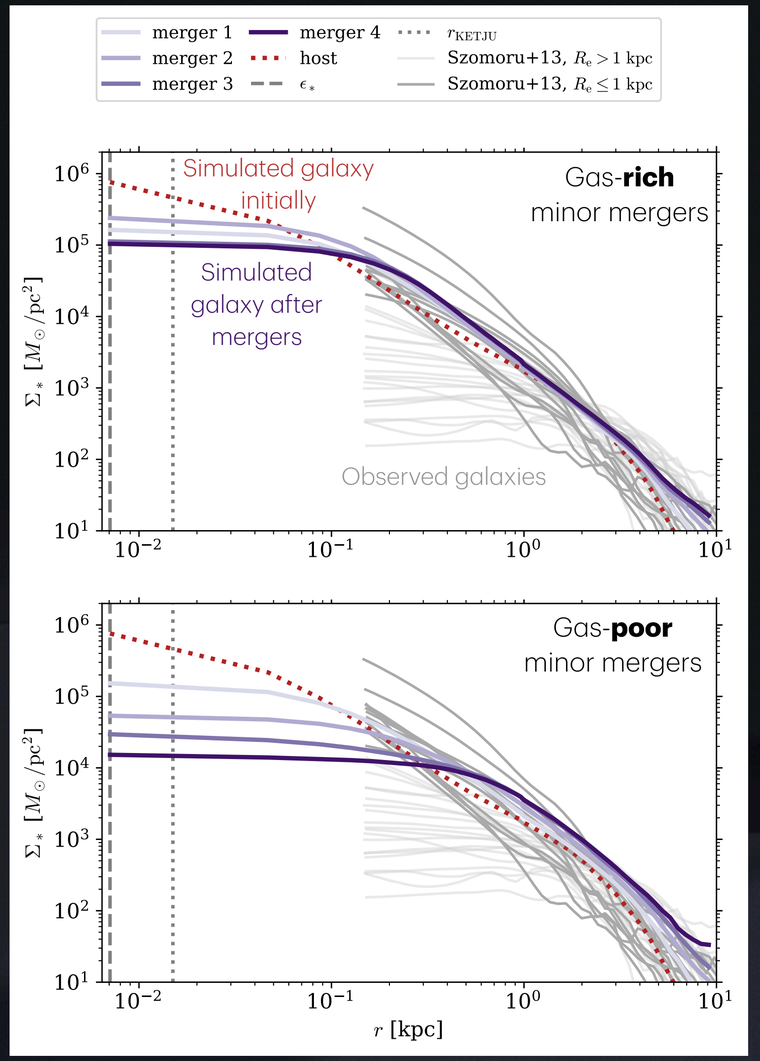
Results

Stellar density evolution

- Central density...
  - increases due to star formation
  - increases due to deposited satellite stars
  - decreases due to stellar ejections by binary BHs
  - decreases due to violent relaxation
- Gas-rich mergers needed to maintain central densities comparable with z ~ 2 red nuggets



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Thank you!
Questions?

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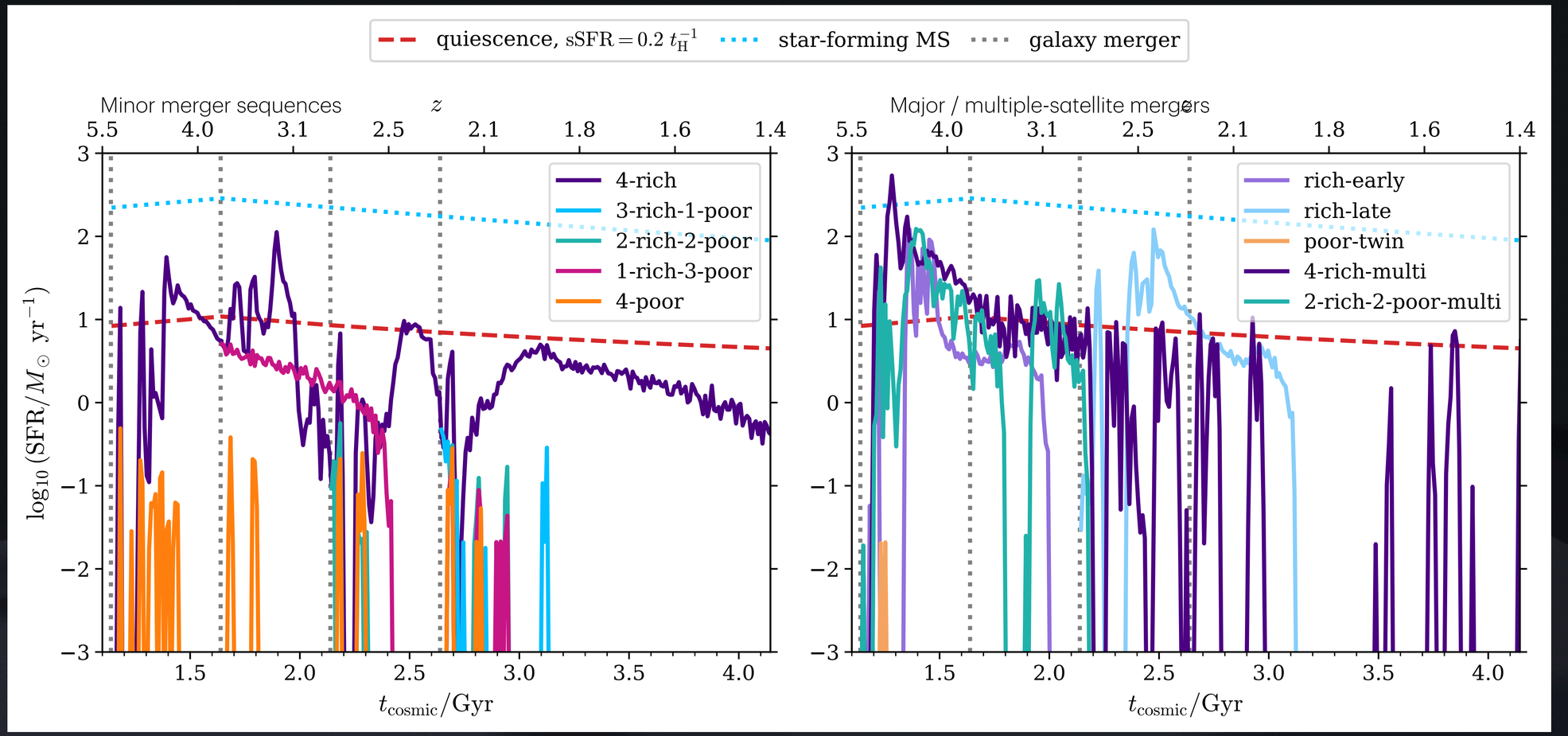
Extra slides

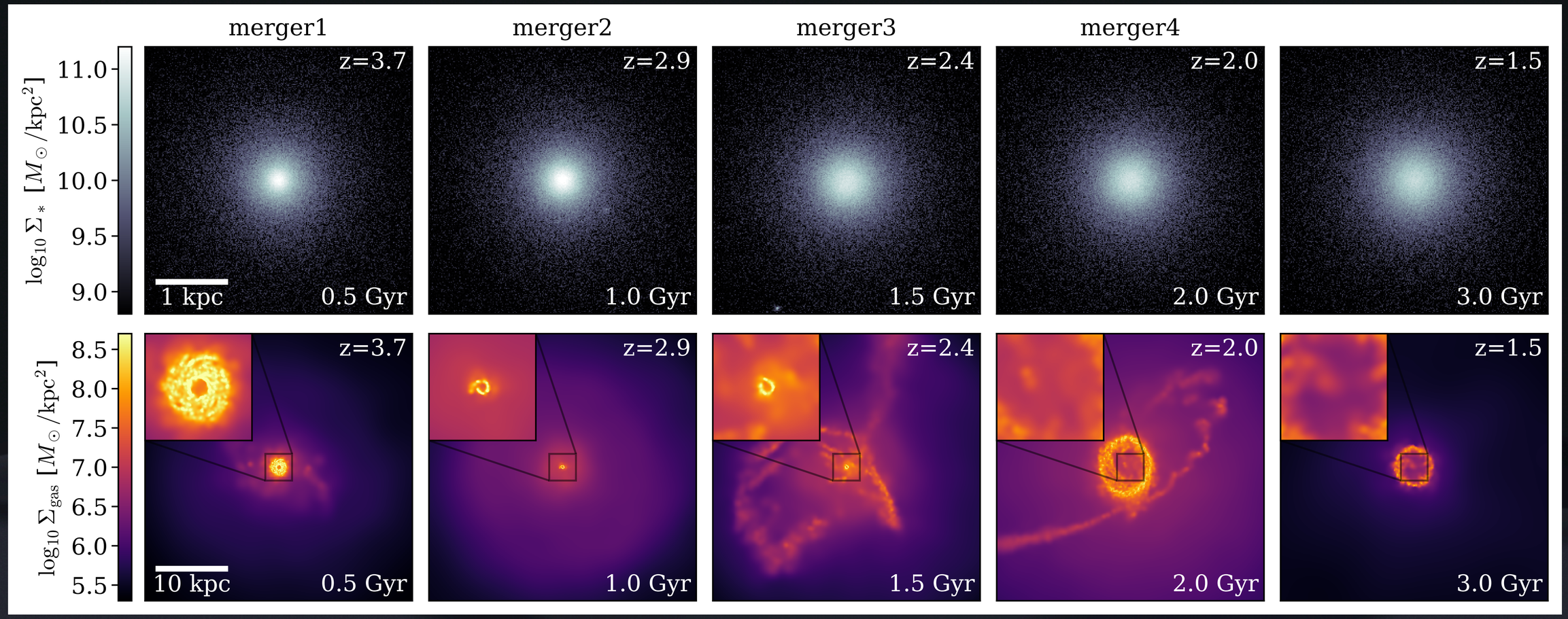
Star formation rate



Mattero+, in prep.

Extra slides

Morphology



Mattero+, in prep.