GAS FLOWS AND STARBURST IN MERGING DWARF GALAXIES

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Theory: Dwarf galaxies

- Low mass, stellar masses of $10^{2\text{-}9}\ M_{sun}$ (MW ~ $10^{12}\ M_{sun}$)
- Up to 80 % of the galaxies in our local volume
- Susceptible to the effects of their own evolution

Image credit [1]

Theory: The interstellar medium (ISM)

- Baryonic matter between stars in a galaxy
- Multiphase ISM – gas can be divided into phases based on temperature and chemical state of hydrogen

Gas state	Temperature	Description
Cold	$T \leq 300$ K	Star forming gas
Warm	$300 \text{ K} < T \leq 20\,000$ K	Atomic and ionized gas from PI
Warm-Hot	$20\,000 \text{ K} < T \leq 300\,000$ K	Highly ionized, cooling SN gas
Hot	$T > 300\,000$ K	Very hot gas from SNe

Theory: Star formation

- Stars form when dense molecular clouds collapse under their own gravity
- Collapse happens when the cloud's mass exceeds Jeans mass

$$\boxed{M_J \propto T^{3/2} \rho^{-1/2}}$$

- Star formation is highly inefficient → $\varepsilon \sim 0.01\text{-}0.02$

Theory: Stellar feedback

- Stars heat, ionize and in other ways affect the surrounding gas, hindering future star formation

- Main sources:
    - Supernovae
    - Photoionization
    - Stellar winds

Image credit [2]

Theory: Galaxy mergers

- Structure formation is hierarchical (or “bottom-up”)
  → larger structure forms through the merging of smaller structures

- The early Universe was smaller than the present Universe
  → distances between galaxies were smaller in the early Universe

→ Dwarf galaxies often undergo mergers

Theory: Gas inflows and outflows

Inflows

Interaction with a merger produces tidal forces

→ Gas is funneled to the centre

Outflows

Clustered supernova explosions create massive cavities in the ISM

→ 'Superbubbles' are able to drive gas out of the disk of the galaxy

Theory: Star clusters

- Star formation is often clustered since molecular clouds fragment before collapse

- A star cluster is essentially a group of stars

- Star clusters often disperse within 10 Myr

Research: Motivation

- Dwarf galaxies offer a great research ground for high resolution simulations and research regarding galactic evolution in the early Universe

Question:

How greatly does the merger interaction affect the radial gas flows, star formation and stellar feedback in a dwarf galaxy?

Research: Simulation code

High-resolution hydrodynamical simulation GRIFFIN (GADGET-3/SPHGal)

- GADGET-3: Smoothed particle hydrodynamics tree code
- SPHGal: Modification of GADGET-3, allows for realization of individual massive stars and subsequently offers a more realistic model of the effects of mass-dependent feedback, also improved treatment of baryonic processes
- Baryonic particle mass resolution of 4 M_{sun}!

For more details see references [3]-[6]

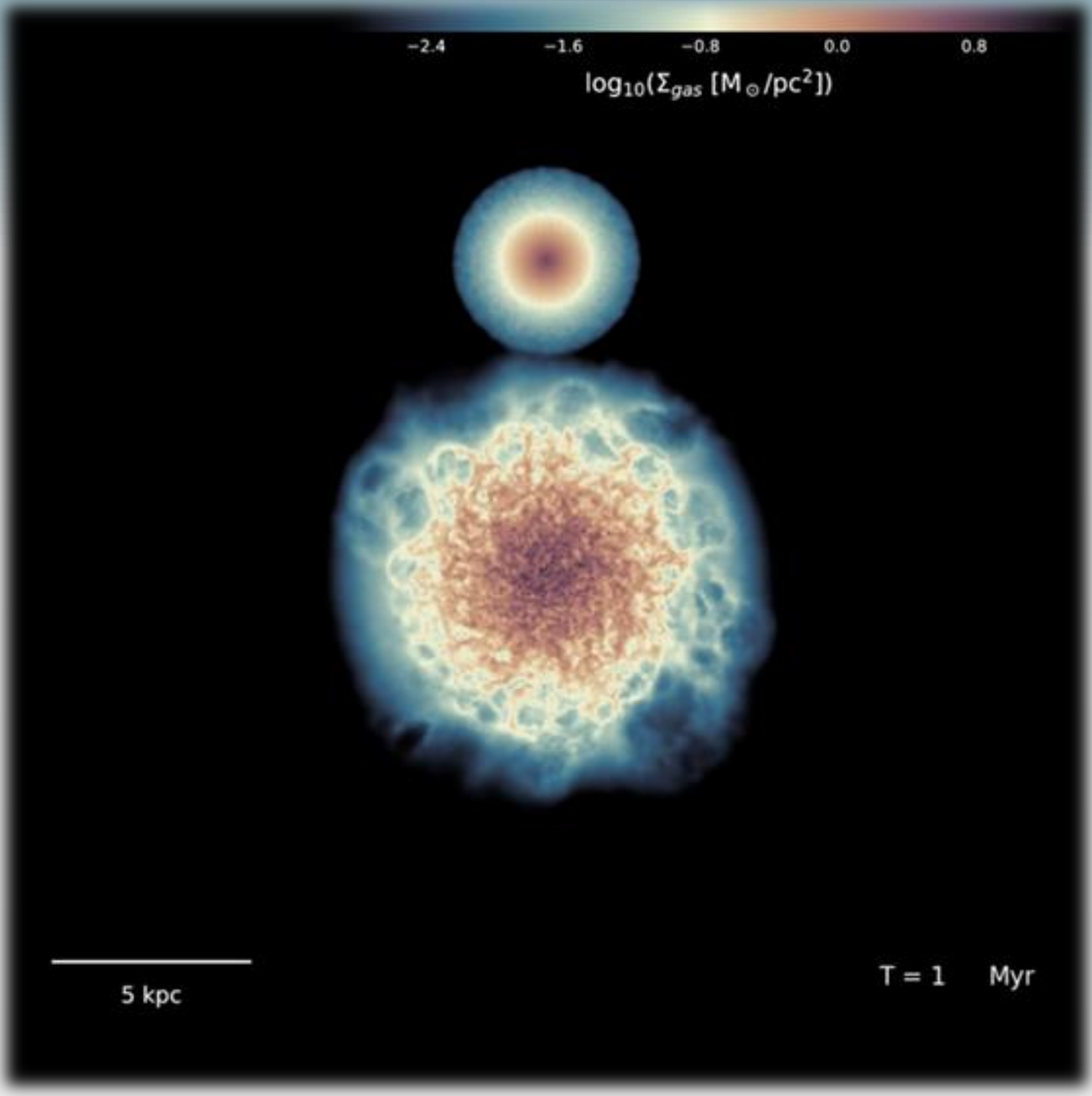
Research: Set-up

<u>Merger</u>

- 10:1 merger of dwarf galaxies
- Size is different, otherwise identical galaxies
- Prograde, in-plane orientation

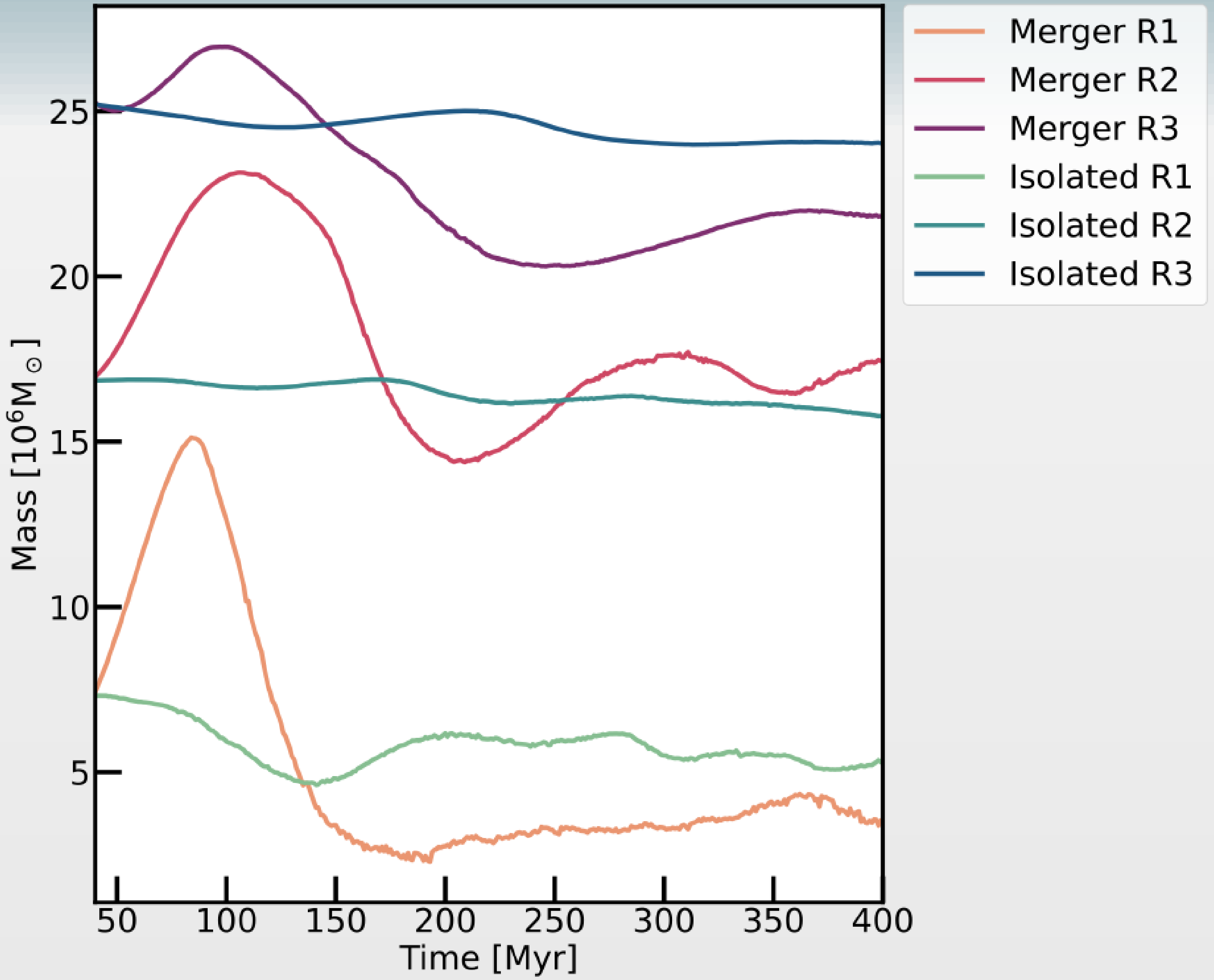
<u>Isolated</u>

- Same as the larger galaxy in the merger system



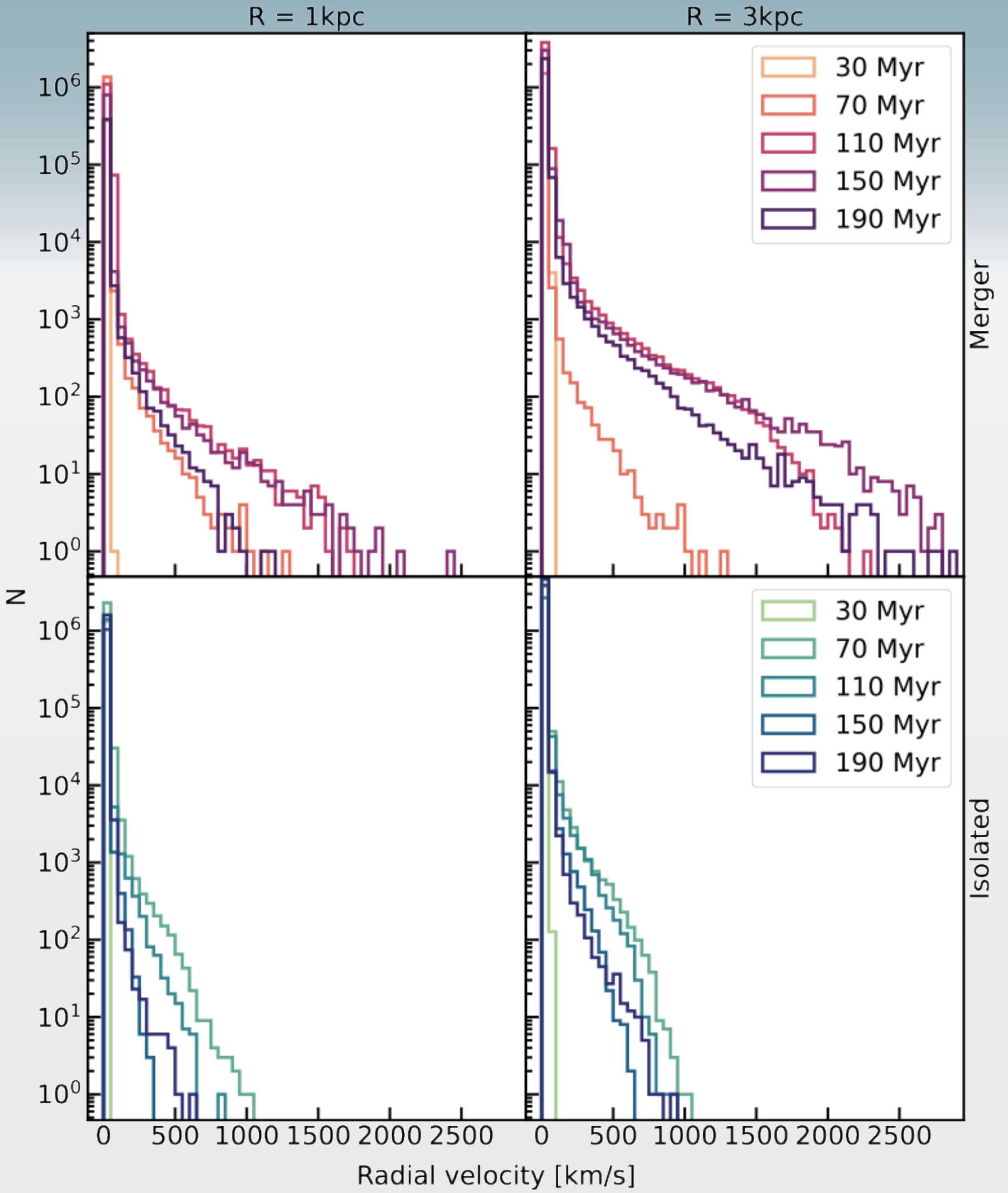
Results: Significant gas inflows

- The mass of gas in the centre of the merger galaxy increases while the smaller galaxy is approaching pericentre



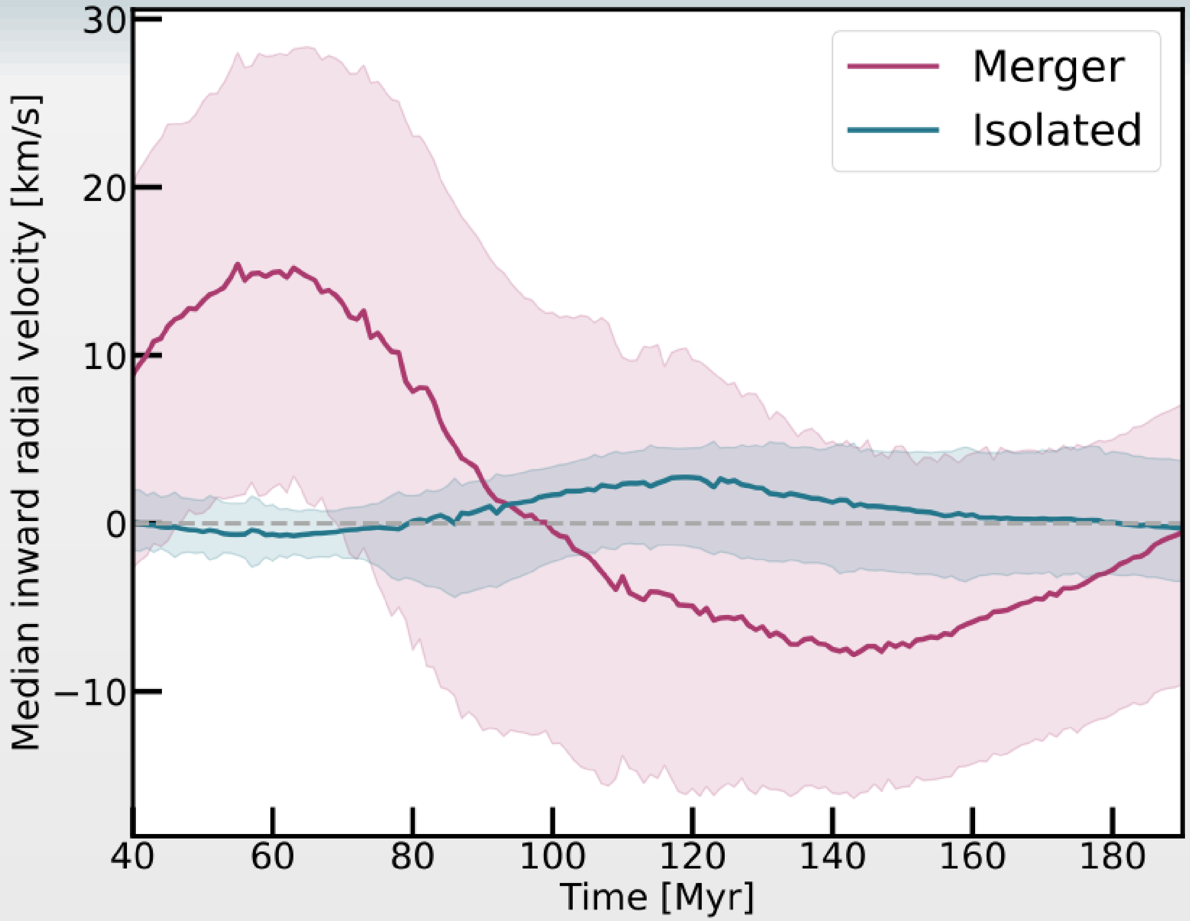
Results: Strong gas outflows

- The merger has much higher outflow velocities
- Indicates a greater number of supernova explosions

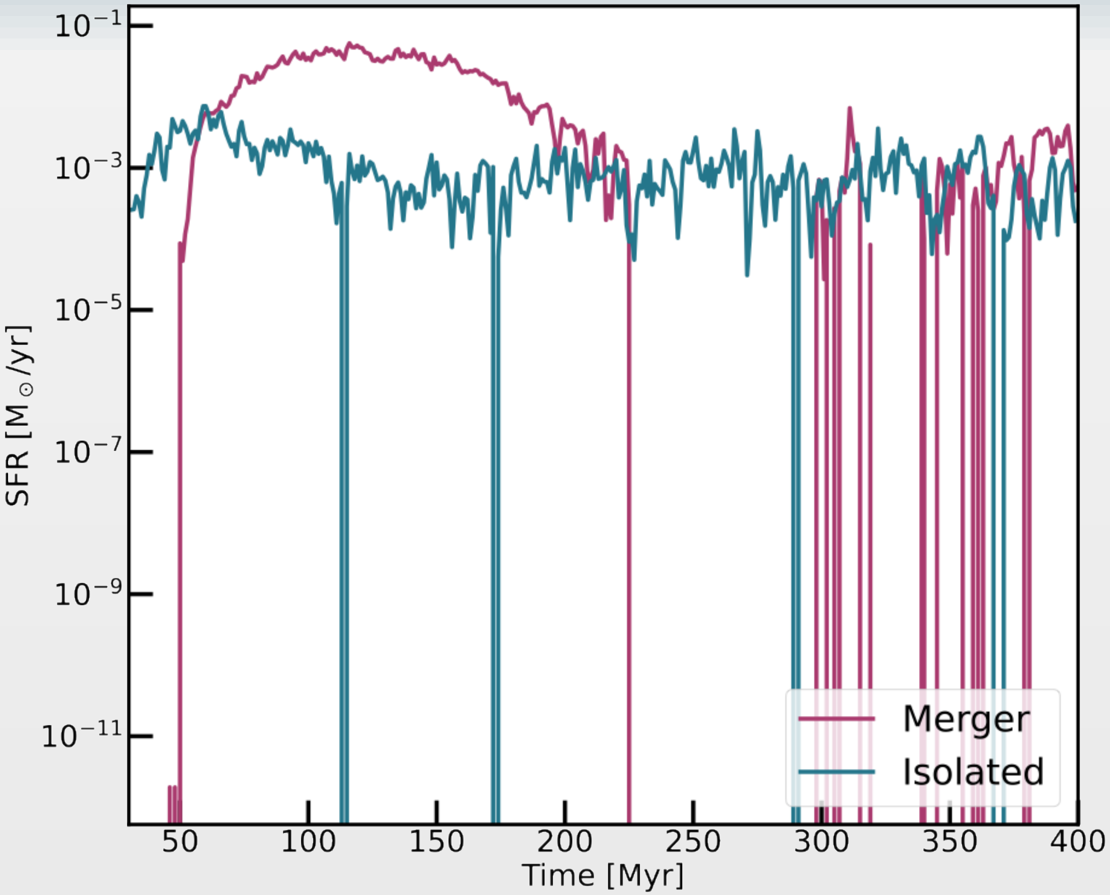


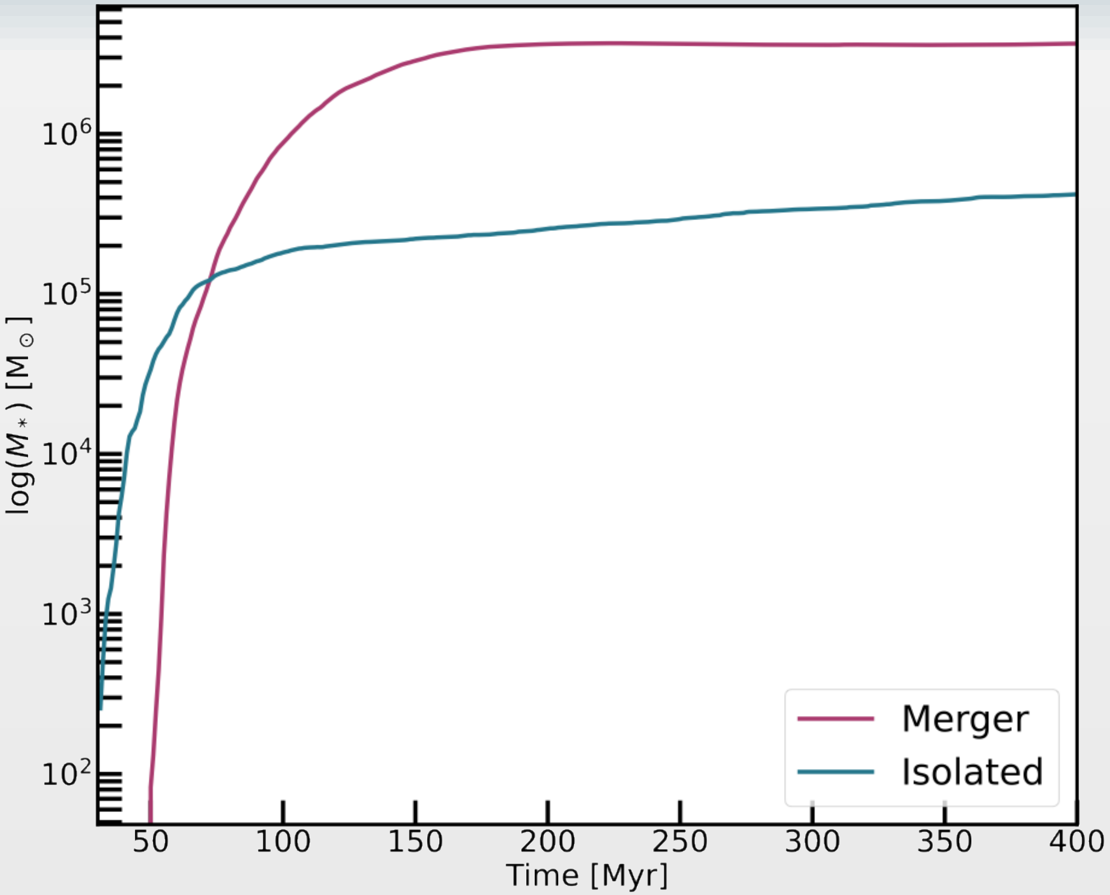
Results: Inflows VS outflows

- Median velocities are higher in the merger
- Merger is dominated by inflows up to t = 100 Myr, then dominated by outflows



Results: Increased star formation rate (SFR)





Results: Starburst

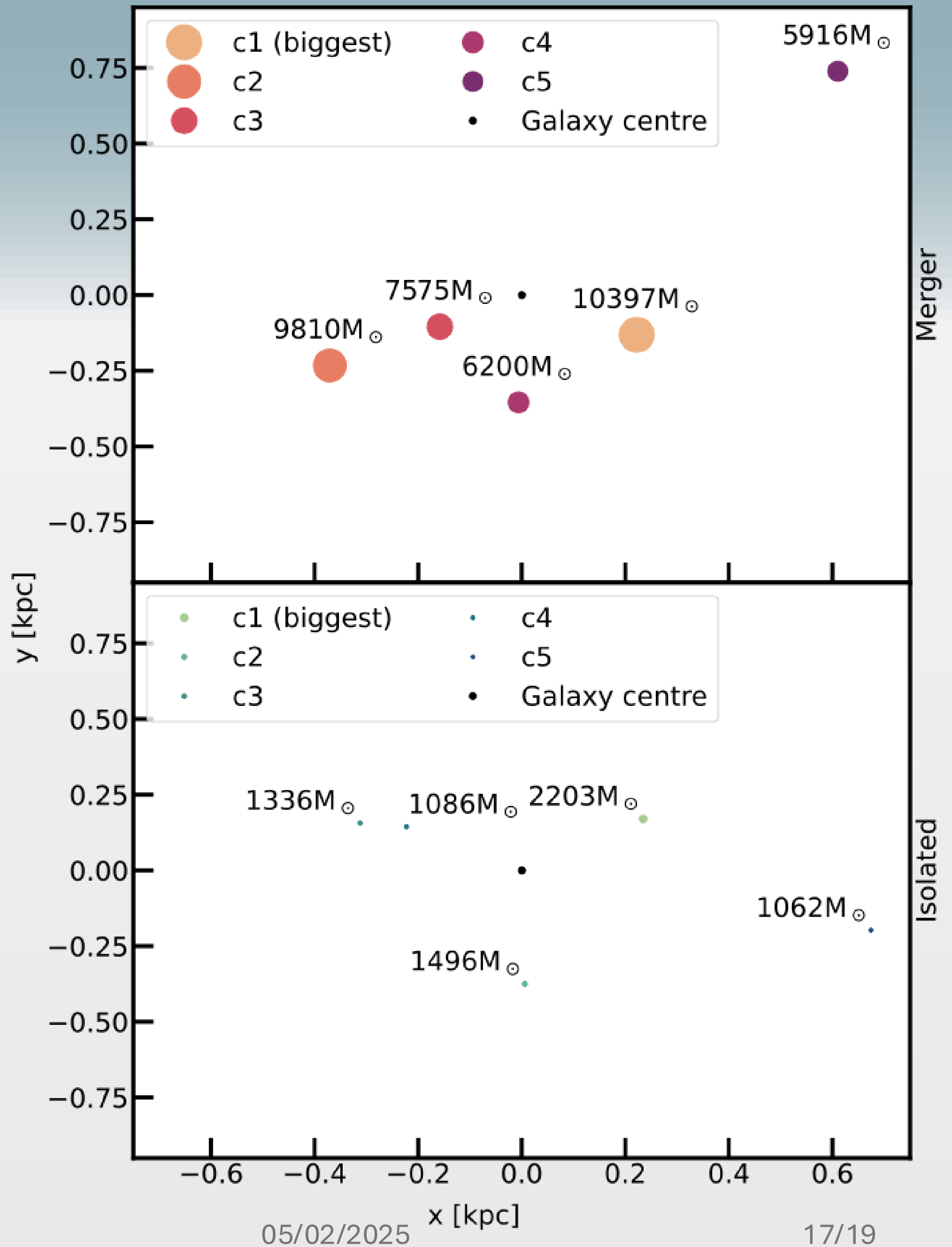
- The increased SFR in the merger leads to quenching of star formation
- The formed stellar mass in the merger is over a magnitude greater than in the isolated

Name	$M_{\mathrm{gas,IC}}$ [$\mathrm{M}_\odot$]	$M_{\mathrm{gas,200Myr}}$ [$\mathrm{M}_\odot$]	$M_{*,\mathrm{IC}}$ [$\mathrm{M}_\odot$]	$M_{*,\mathrm{formed}}$ [$\mathrm{M}_\odot$]
`isolated`	4×10^7	3.8×10^7	2×10^7	2.6×10^5
`merger`	4×10^7	2.5×10^7	2×10^7	3.7×10^6

Results: Massive star clusters

- The most massive cluster in the merger is ~ 5 times bigger than the most massive cluster in the isolated

- A merger interaction is likely required to create clusters that are massive enough to drive superbubbles and outflows



Results

Merger

→ Significant inflows and outflows

→ Hot gas and superbubbles

→ Increased star formation

→ Massive star clusters

Isolated

(purposefully left blank for dramatic effect)

Summary

- Merger interactions are frequent for dwarf galaxies
- Simulation results show that the interaction greatly affects the evolution of the galaxy
- Results provide concrete insight as to how galaxy mergers shape the evolution of low-mass galaxies, and subsequently the evolution of larger structures in the Universe.

References:

[1] Andrei Bacila, https://skyandtelescope.org/online-gallery/m81-m82-and-their-violent-past/ (visited 2/2/2025)

[2] X-ray: NASA/CXC/PSU/L.Townsley et al.; Optical: NASA/STScI; Infrared: NASA/JPL/PSU/L.Townsley et al.

[3] Volker Springel, The cosmological simulation code GADGET-2, *Monthly Notices of the Royal Astronomical Society*, Volume 364, Issue 4, December 2005, Pages 1105–1134, https://doi.org/10.1111/j.1365-2966.2005.09655.x

[4] Chia-Yu Hu et al., SPHGal: smoothed particle hydrodynamics with improved accuracy for galaxy simulations, *Monthly Notices of the Royal Astronomical Society*, Volume 443, Issue 2, 11 September 2014, Pages 1173–1191, https://doi.org/10.1093/mnras/stu1187

[5] Chia-Yu Hu et al., Star formation and molecular hydrogen in dwarf galaxies: a non-equilibrium view, *Monthly Notices of the Royal Astronomical Society*, Volume 458, Issue 4, 01 June 2016, Pages 3528–3553, https://doi.org/10.1093/mnras/stw544

[6] Chia-Yu Hu et al., Variable interstellar radiation fields in simulated dwarf galaxies: supernovae versus photoelectric heating, *Monthly Notices of the Royal Astronomical Society*, Volume 471, Issue 2, October 2017, Pages 2151–2173, https://doi.org/10.1093/mnras/stx1773

Thank you for listening
Ask questions!