Clash of ~~titans~~ dwarfs:

Merger and interaction driven evolution in the dwarf regime

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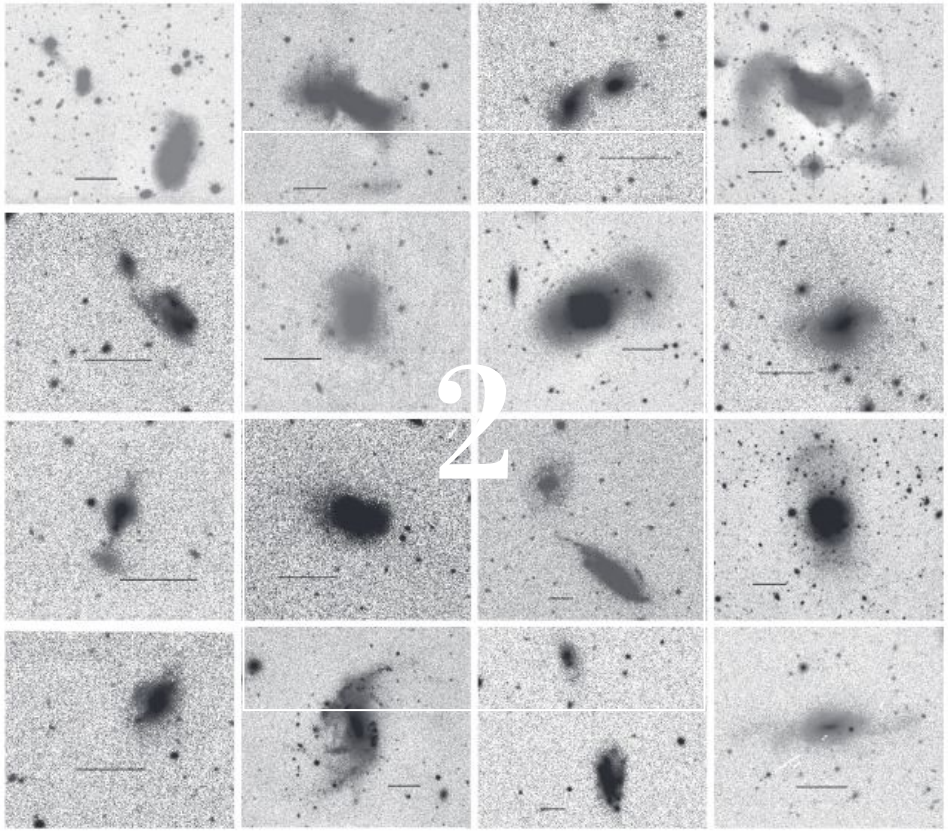


Examples of interacting or merging dwarfs from **Paudel+18**'s catalogue

Mergers and interactions in the dwarf regime

- Like all galaxies, dwarfs galaxies can exhibit low surface brightness (**LSB**) features or disturbed morphologies that can reveal information about their interaction history (e.g. **Rich+12**; **Martínez-Delgado+12**; **Johnson+2013**; **Paudel & Sengupta 17**; **Besla+18**).

- Detailed imaging of LSB features is accessible in the local Universe (e.g. **Paudel+18**) and can be used to give a somewhat accurate idea of the processes that at play.

Martin et al. 2020 arXiv:2007.07913

3

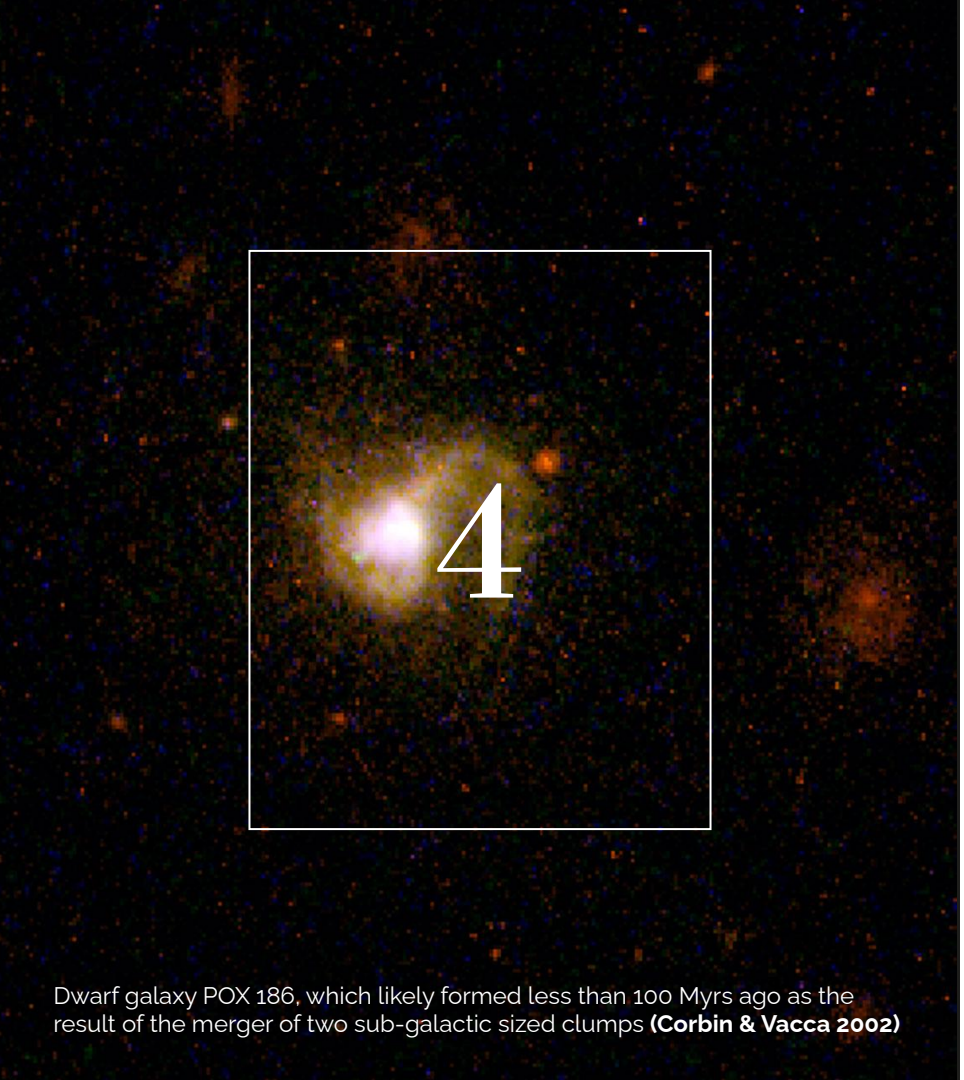
The Vera Rubin Observatory under construction at Cerro Pachon in Chile.

➔ Deeper observations available from e.g. LSST, JWST will allow us to discover large samples of merging and interacting dwarf galaxies.

➔ But in many cases, it remains difficult to disentangle mergers from other types of interactions - especially as deep surveys make the more distant Universe accessible for studies of this nature.

Left: Tidal features visible with SDSS, Decals (2 mag deeper), HSC (4 mag deeper)

Right: SDSS vs HSC 30 min exposure (**Montes+2021**)



Dwarf galaxy POX 186, which likely formed less than 100 Myrs ago as the result of the merger of two sub-galactic sized clumps **(Corbin & Vacca 2002)**

Questions

- We believe that dwarf-dwarf mergers are fairly uncommon (e.g. **Deason+14**). So are morphological disturbances a good indicator of a merger having taken place in the dwarf regime?

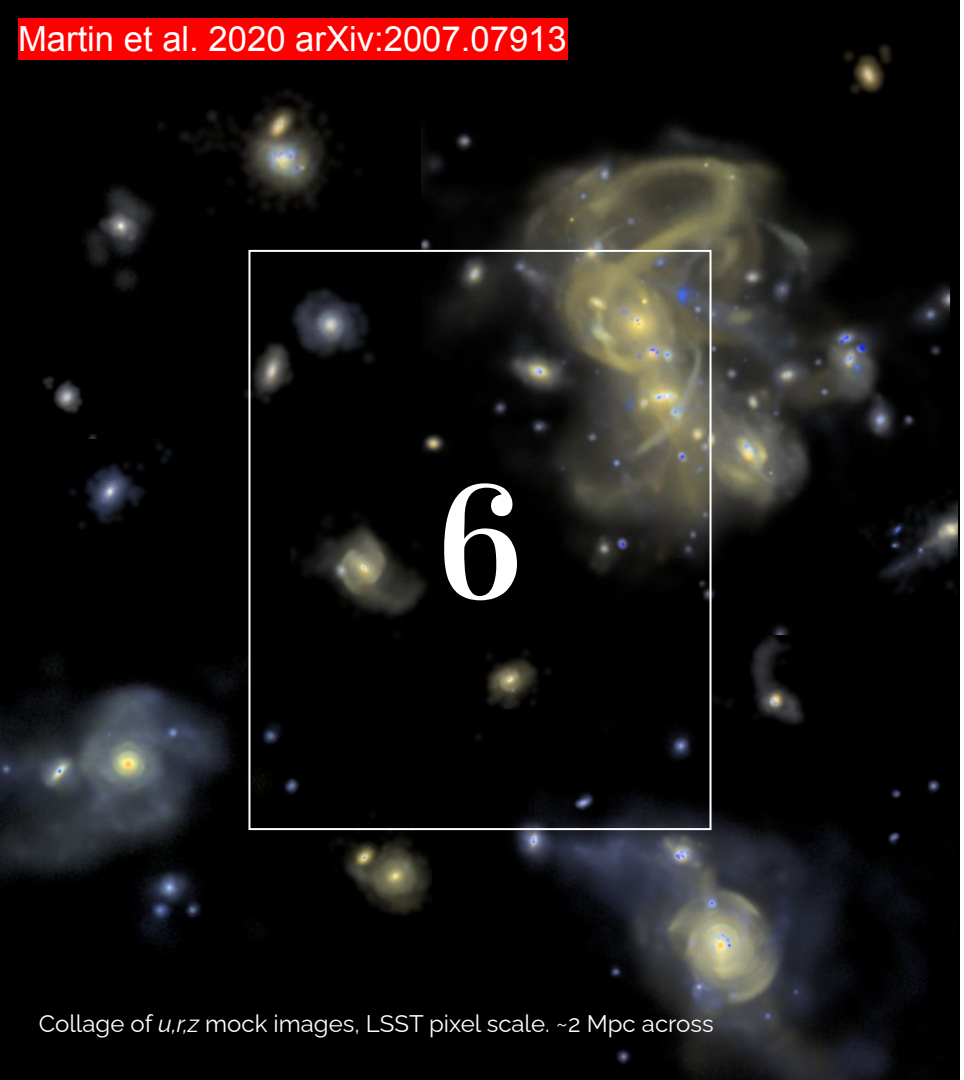
- How is mass assembled in the dwarf regime. Are interaction driven starbursts (e.g. **Besla+18**) important, and what proportion of star formation is triggered by interactions and mergers?

Martin et al. 2020 arXiv:2007.07913

Mock images of two galaxies in the New Horizon simulation produced using the SKIRT radiative transfer code.

The NewHorizon Simulation (Dubois+20)

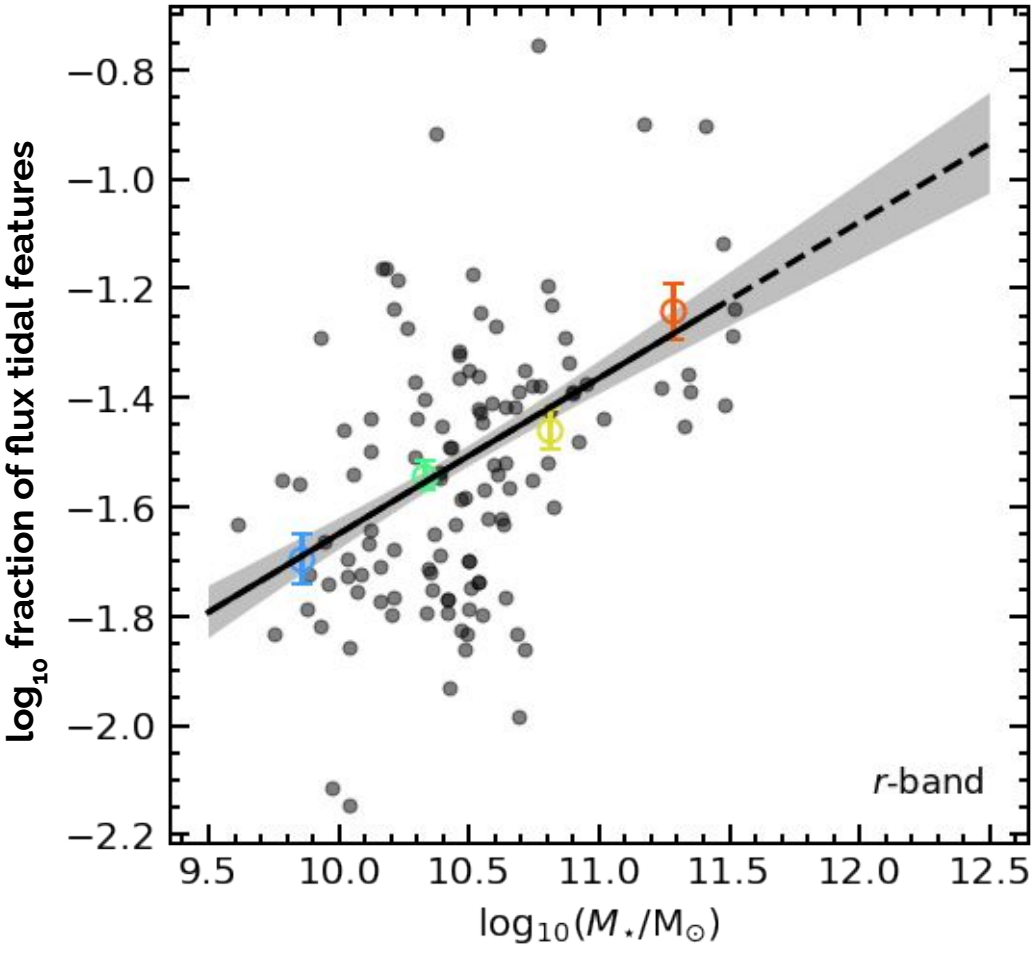
- ➔ High spatial and stellar mass resolution cosmological simulation: **34 pc / 10^4 M⊙**.
- ➔ Metal-dependent gas cooling down to 0.1K (!).
- ➔ Federrath-like star-formation criterion (efficiency depends on the local turbulent mach number and virial parameter).
- ➔ Volume is a 10 Mpc radius sphere (zoom in of an 'average' volume of the Horizon-AGN simulation.
  - ◆ ~3000 dwarf galaxies in **field and group environments**.



Collage of *u,r,z* mock images, LSST pixel scale. ~2 Mpc across

Aim

- ➔ Use the NewHorizon Simulation to examine the relative importance of mergers vs other interactions in the dwarf regime over cosmic time
- ➔ Determine their importance in driving the assembly of dwarfs



Plot: fraction of r-band flux found in tidal features as a function of stellar mass **(Martin+ in prep)**

Do mergers drive morphological disturbances in low mass galaxies?

- ➔ In low mass galaxies very little flux is found in tidal features compared to more massive galaxies
- ➔ But may still exhibit morphological disturbances

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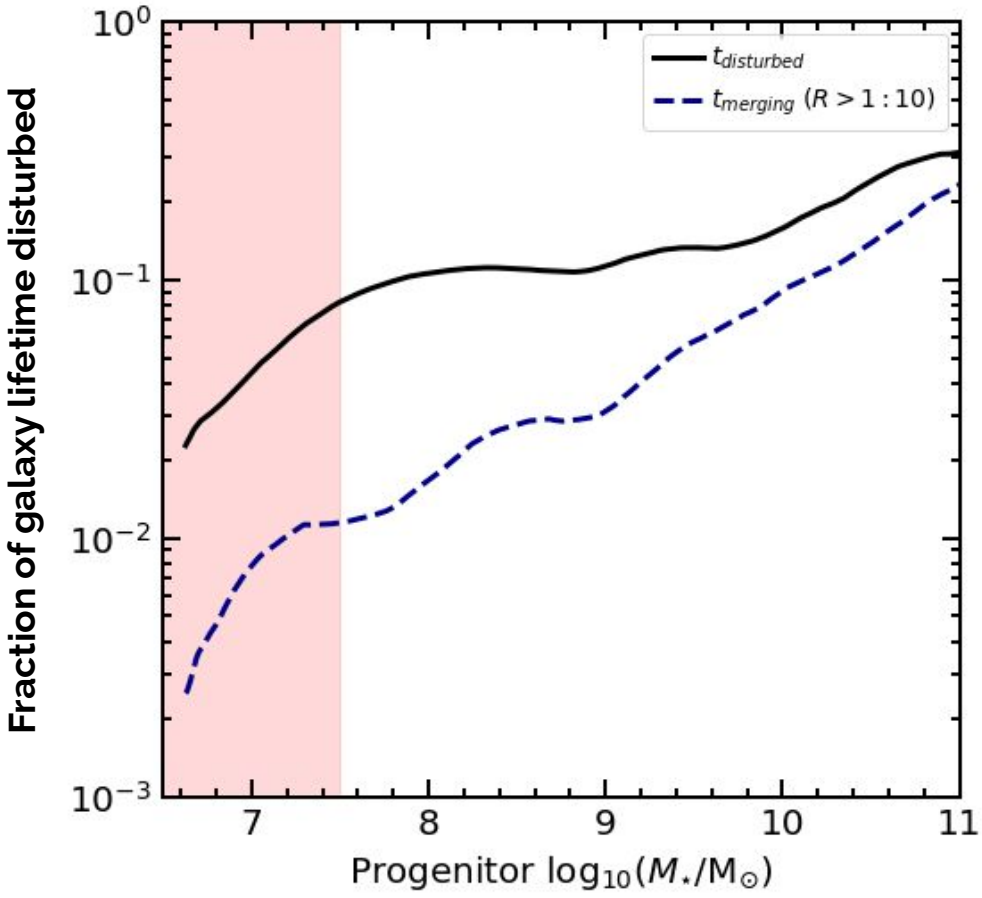

Plot: fraction of galaxy lifetime spent in a morphologically disturbed state as a function of stellar mass

Do mergers drive morphological disturbances in low mass galaxies?

- ➔ In low mass galaxies very little flux is found in tidal features compared to more massive galaxies
- ➔ But may still exhibit morphological disturbances
- ➔ Galaxies exist in a **disturbed state for 10% - 30% of their lifetime** on average.
  - ◆ Limited change as a function of mass.
- ➔ But mergers are more likely to drive this for higher masses.
- ➔ For **dwarf masses**, it is increasingly likely to be **driven by fly-bys**.

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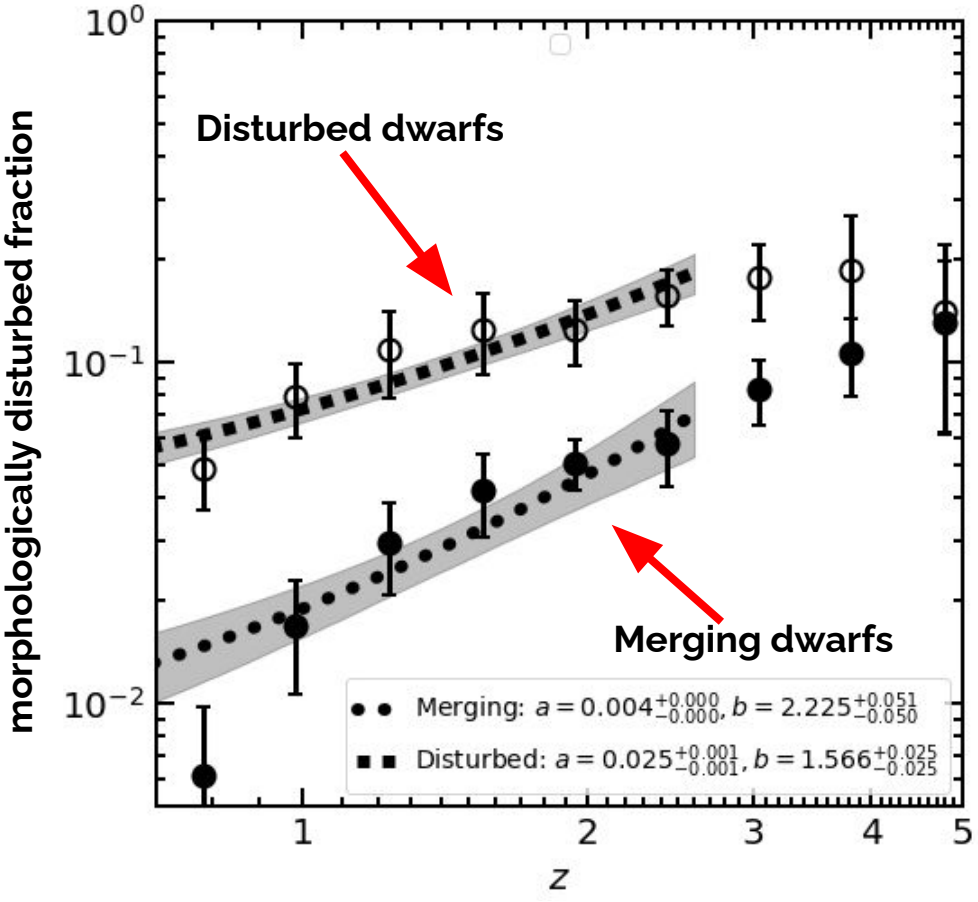
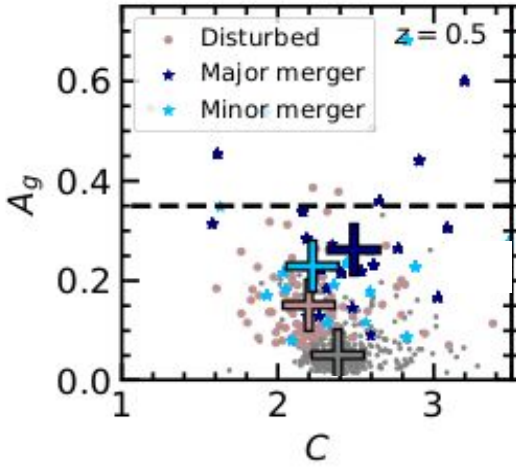


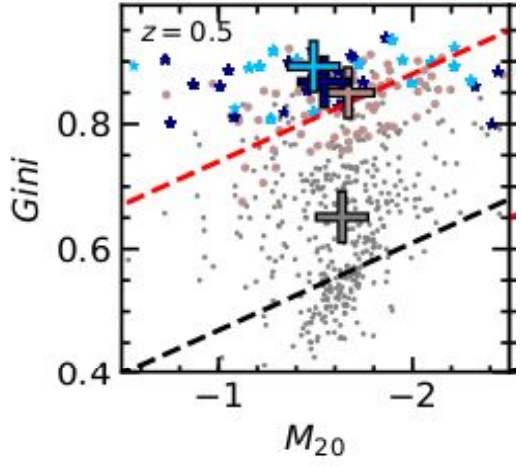
Plot: fraction of merging galaxies and disturbed galaxies vs redshift

Do mergers drive morphological disturbances in low mass galaxies?

- ➔ The **merger fraction** drops somewhat more steeply (**power law index=2.25**) than the fraction of **morphologically disturbed galaxies** (**power law index=1.5**) with redshift.
- ➔ Mergers become unimportant in the dwarf regime at low redshift, but disturbed morphologies as a result of **fly-bys could remain significant**.

Martin et al. 2020 arXiv:2007.07913





Do mergers drive morphological disturbances in low mass galaxies?

- ➔ Morphological disturbances are not a proxy for mergers in the dwarf regime -- **much more likely to be the result of fly-bys etc**.
- ➔ Merging galaxies and galaxies disturbed by fly-bys occupy similar or overlapping regions of parameter space, however.
- ➔ Consequences for studies of the dwarf regime
  - e.g. calculating merger rates in the dwarf regime.
  - Determining triggering mechanisms of starbursts.

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Galaxies in the HST CANDELS GOODS-South Field.

Do mergers and fly-bys drive a significant proportion of mass assembly in dwarfs?

- ➔ Do we expect interactions to be important in the evolution and assembly of dwarf galaxies
- ➔ Direct assembly from accreted ex-situ formed stellar mass
- ➔ SF enhancements driven by mergers and fly-bys

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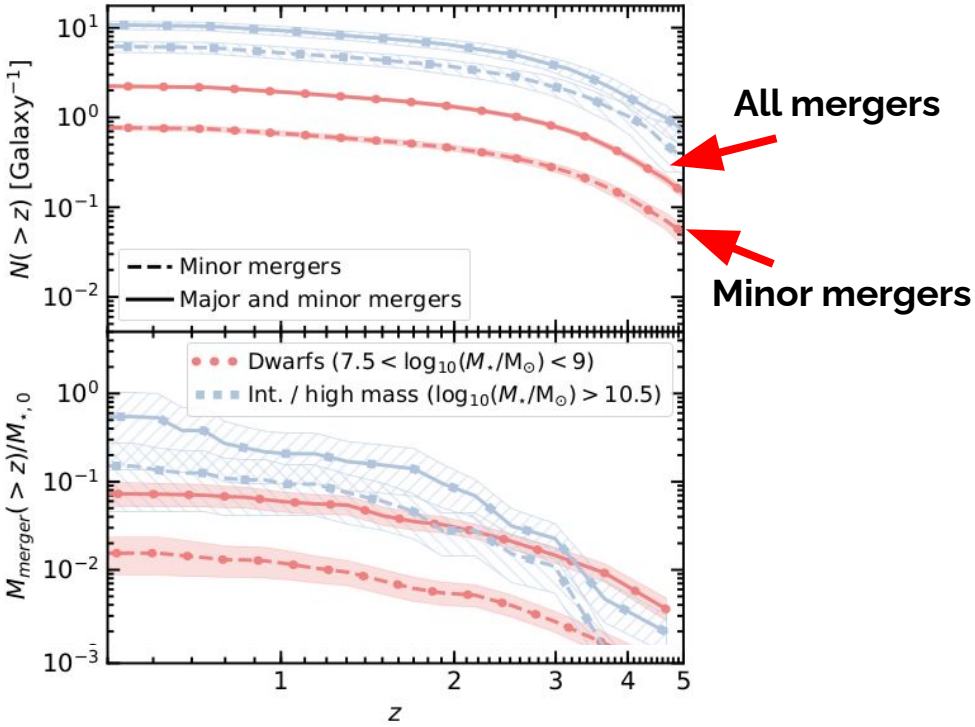
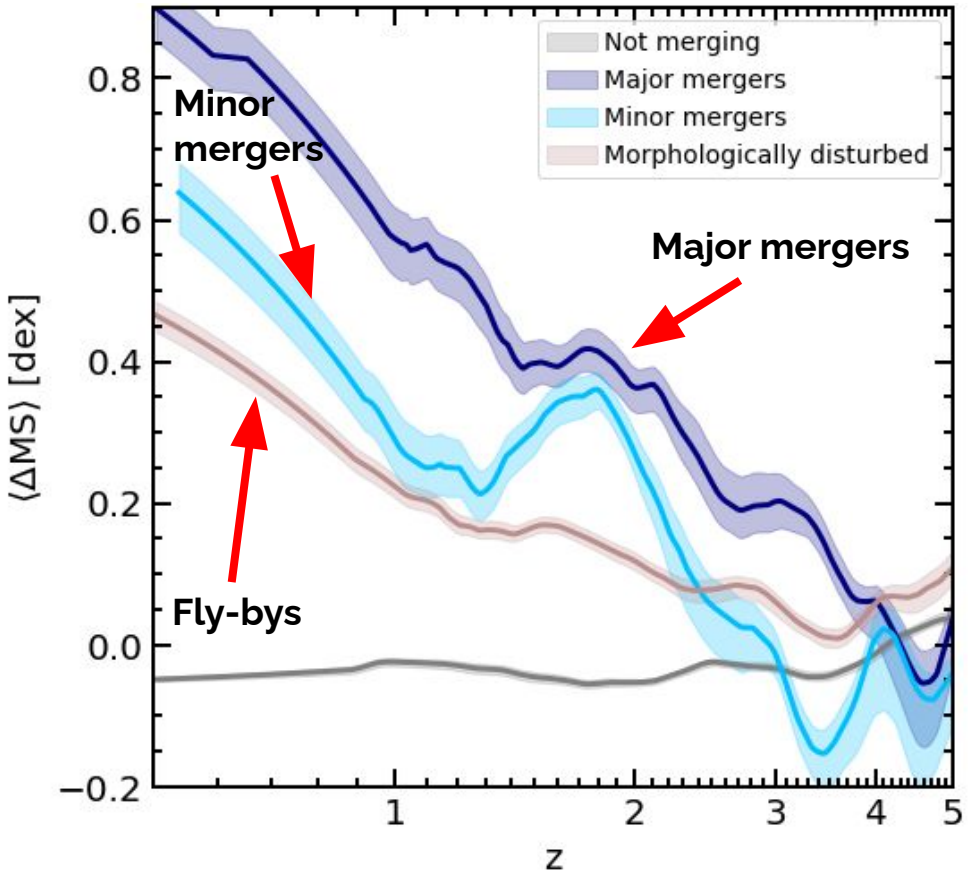
Ex-situ mass



Plot: cumulative number of mergers and cumulative mass fraction from mergers vs redshift

- ➔ Dwarf galaxies undergo one major merger and one minor merger on average (similar to **Deason+14** and others)
- ➔ This accounts for ~10% of their total stellar mass.
  - ◆ Mini mergers (mass ratio < 1:10) likely bring in a similar amount of mass as minor mergers.
- ➔ More massive galaxies undergo at least an order of magnitude more mergers and the majority of their stellar mass is formed ex-situ.

Martin et al. 2020 arXiv:2007.07913



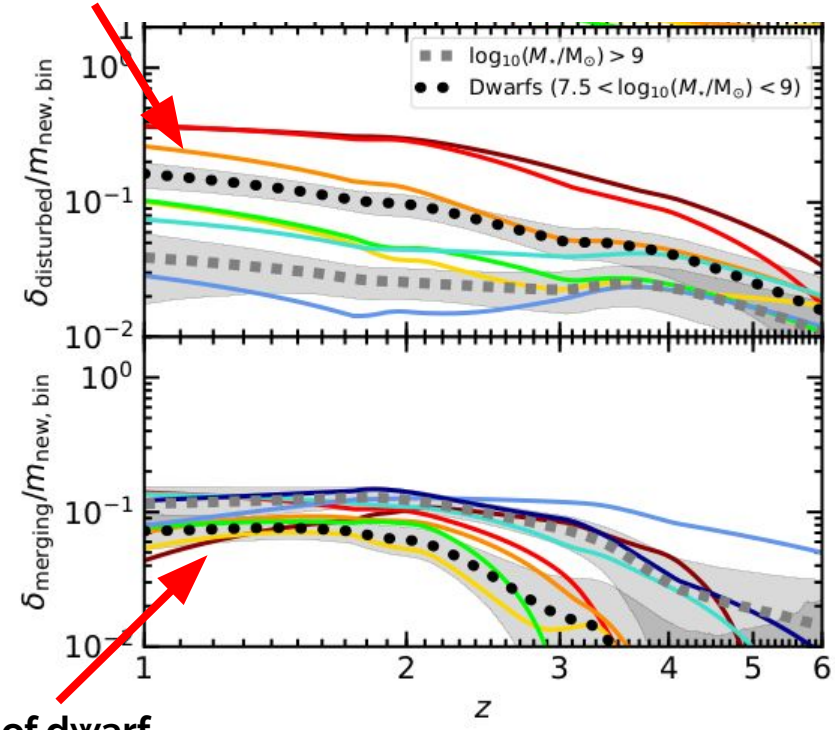
Plot: average displacement from the star forming main sequence

Do mergers drive starbursts and star formation in dwarf galaxies?

- Average SFR enhancement above the main sequence increases towards lower redshift.
- At **lower redshifts**, merging and disturbed galaxies are **consistently more star forming** than average for all masses. There is a somewhat smaller enhancement due to interactions, but they are a lot more numerous than mergers.
- While interactions are not important as triggers of SF in the early Universe (e.g. **Mihos+1997**; **Brosch+04**), they appear to become increasingly important in the low-z Universe.

Martin et al. 2020 arXiv:2007.07913

Fraction of dwarf SFR budget driven by fly-bys

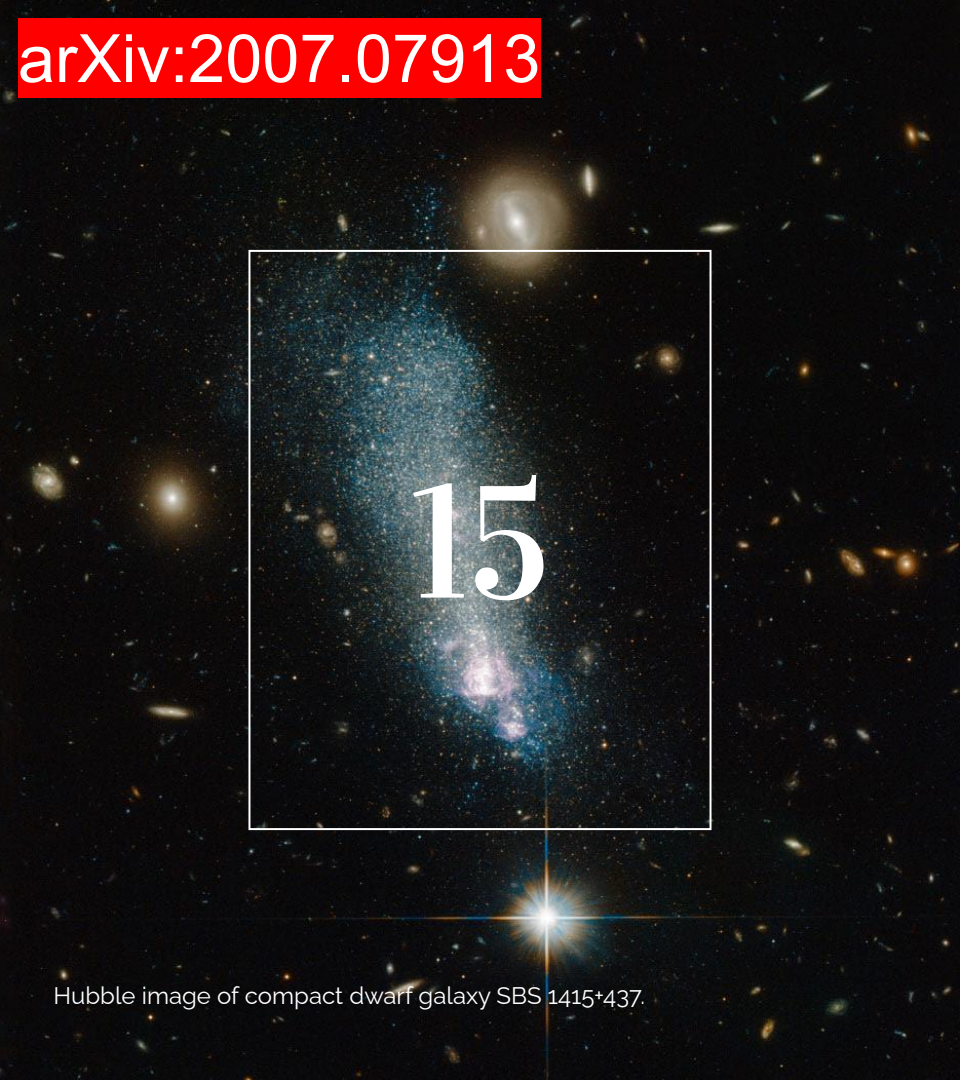


Fraction of dwarf SFR budget driven by mergers

In-situ mass

- We can compare the sSFR of merging/interacting and non-interacting dwarfs to fraction of the star formation budget that is driven directly by merger/fly-by driven SF enhancements.
- Fly-bys drive an increasingly large proportion of the SF budget towards lower redshifts
  - Mergers drive a relatively steady proportion as the merger rate falls rapidly, but SF enhancement increases
- In total, mergers only drive a few per cent of the star formation budget in the dwarf regime but fly-bys drive around 10%.

Martin et al. 2020 arXiv:2007.07913



Hubble image of compact dwarf galaxy SBS 1415+437.

Conclusion

- ➔ Fly-bys or other non-merger interactions drive most of the morphological disturbances in dwarf galaxies.
- ➔ JWST will be capable of separating interacting and non-interacting galaxies.
  - ◆ but great care will be needed to interpret disturbed galaxies, as it will be difficult to disentangle mergers and fly-bys.
- ➔ Mergers and interactions drive a non-negligible fraction (~25%) of mass assembly in the dwarf regime.
  - ◆ From ex-situ sources - 10%.
  - ◆ From SF enhancement from mergers / fly-bys - 5% / 10%.