Relaxation timescales of stellar-gas kinematic misalignments in EAGLE galaxies

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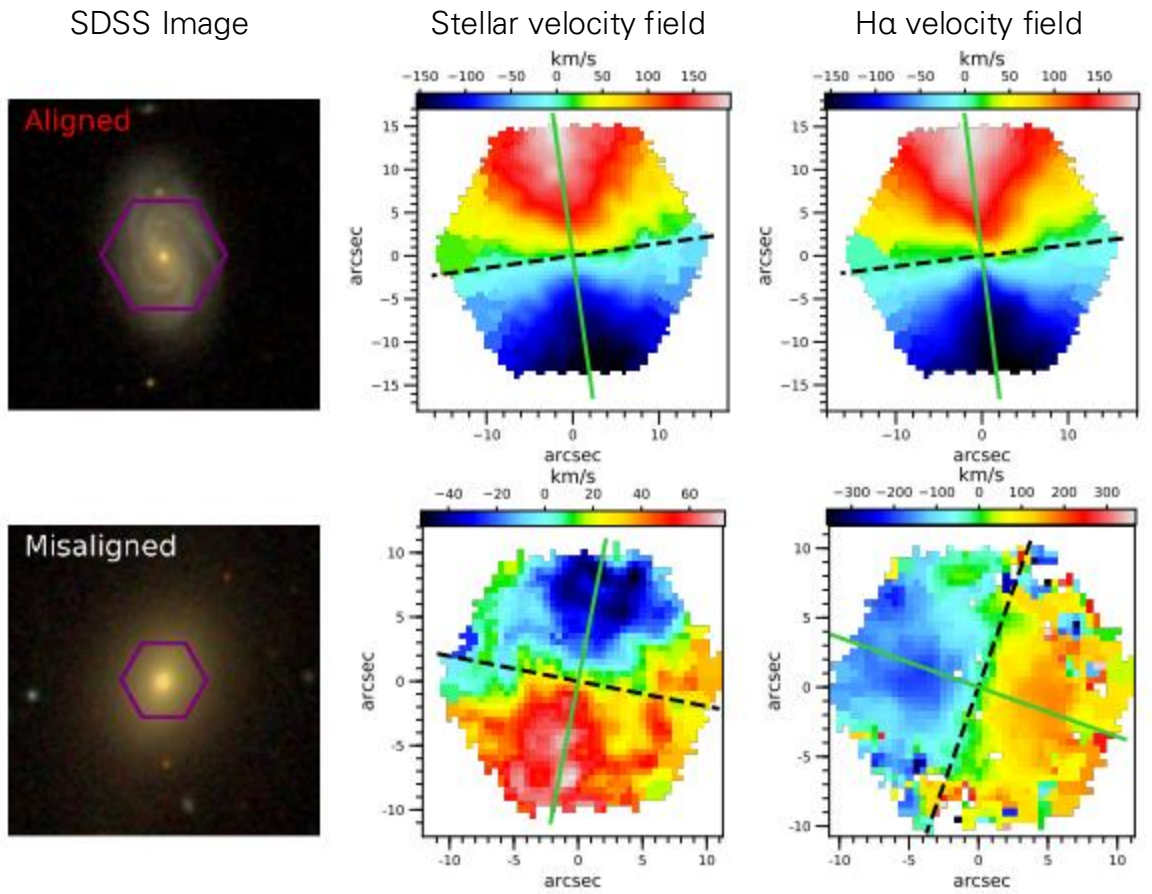
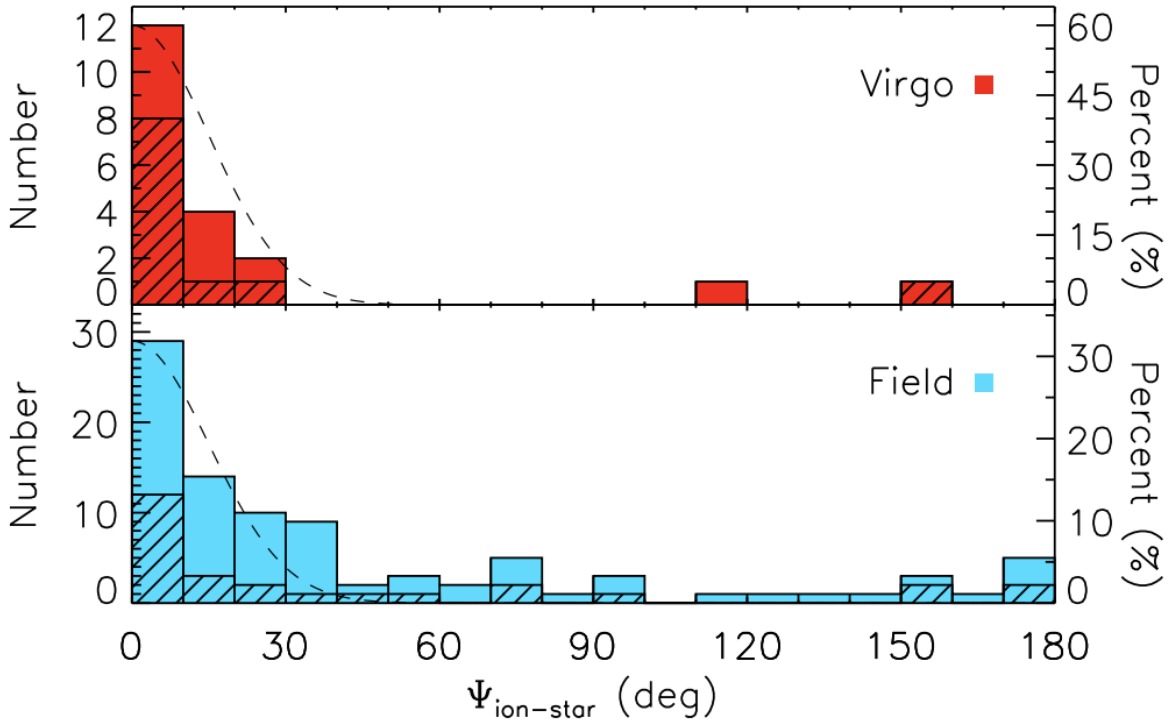


Duckworth et al. (2019)

Misalignments and gas replenishment

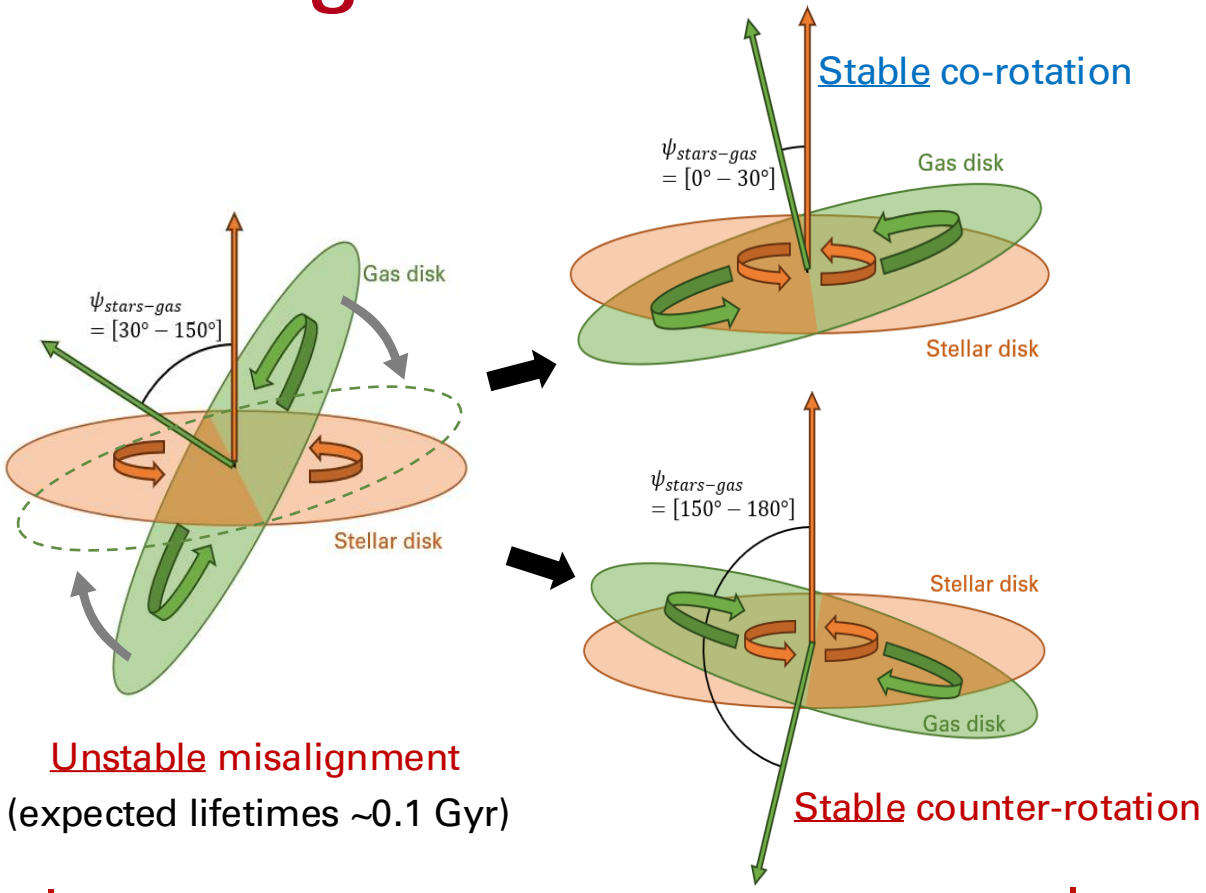
- Significant molecular gas reservoirs found in ~20% of local ETGs (Young et al. 2014, Davis et al. 2019).
  - Many ETGs show signs of recent cold gas replenishment, but dominant physical driver is unresolved.

- Misalignments trace recent accretion/replenishment of misaligned gas (Bryant et al. 2019, Khim et al. 2021).
  - Transient phenomenon with expected lifetimes of ~0.1 Gyr for a typical ETG.
  - Seen in 30 – 40% of Hα-detected ETGs, and ~7% of LTGs (Davis et al. 2011, Bryant et al. 2019).



Distribution of misalignment angles in ETGs | Davis et al. (2011)

Misalignment relaxation timescales



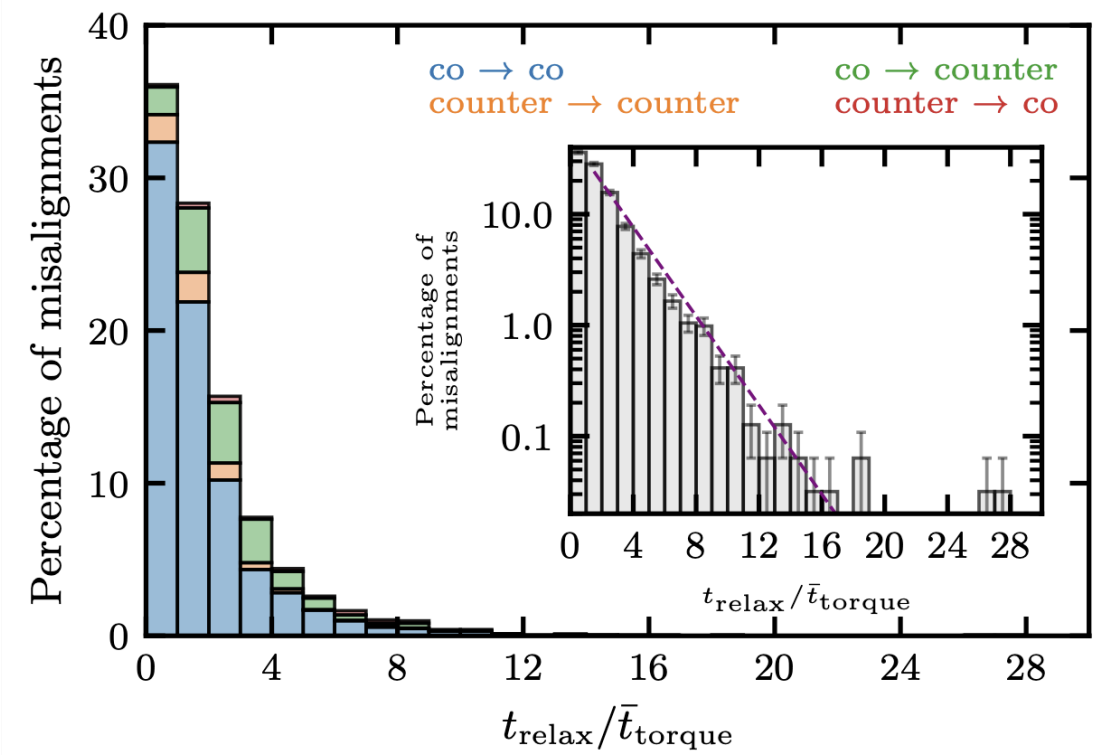
Schematic of a misalignment relaxation

Measured relaxation time / Theoretical relaxation time

- Unstable misalignments 'relax' into the galactic plane, either returning to co-rotation or forming counter-rotation.
- Merger-driven replenishment/formation + short duration misalignments cannot explain observed misalignment distributions (Davis & Bureau 2016).
  - One proposed solution is a dominant population of long-lived misalignments ($t_{relax}/t_{torque} \gg 1$)
- We use EAGLE to investigate typical misalignment timescales for a large representative galaxy population with $M_* > 10^{9.5}\mathrm{M}_\odot$ for the first time.

t_{relax}/t_{torque} distributions

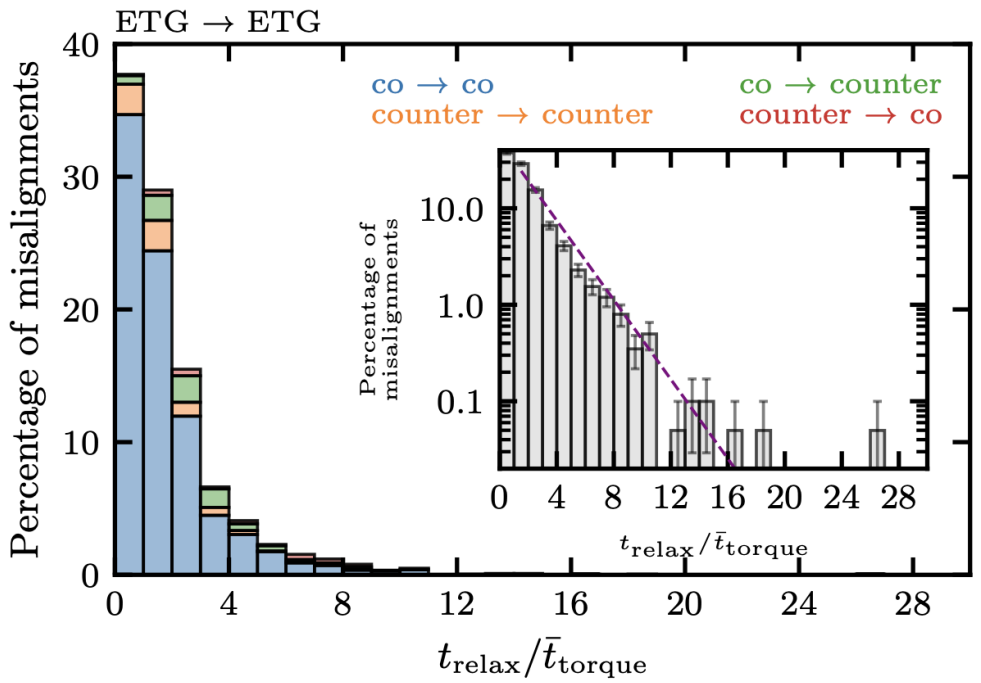
- **Median ratios of $t_{relax}/t_{torque} \approx 1.4$** suggest most galaxies relax on short timescales in the absence of smooth accretion.
- Relaxation timescales and ratios described by a log-linear distribution.
- A population of long relaxations exist, with **$\approx 20\%$ of all misalignments with $t_{relax}/t_{torque} > 3$**



Baker et al. (2025)

t_{relax}/t_{torque} distributions: ETGs

Baker et al. (2025)

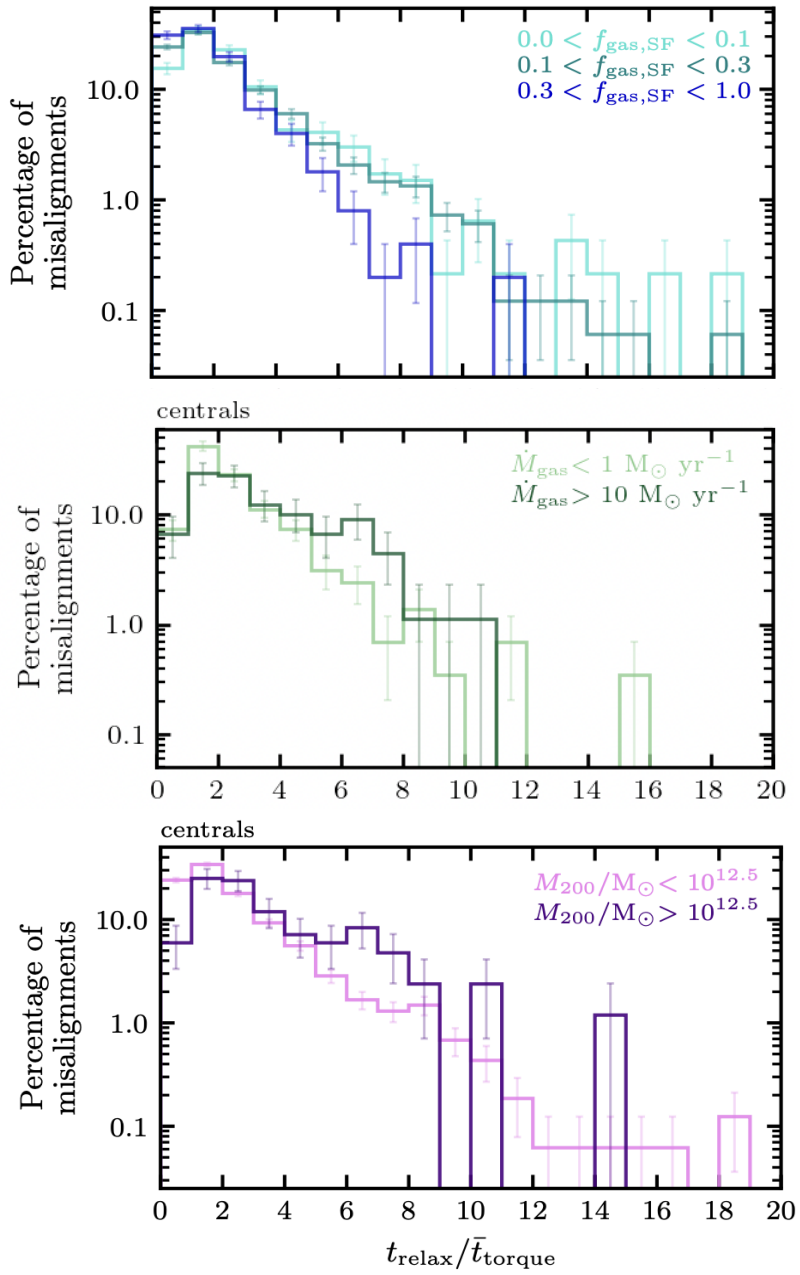


- **No dominant population of $t_{relax} \gg t_{torque}$ in ETGs → long-lived misalignments are rare.**
- Instead, misalignment events tend to occur frequently and often displaced by small angles ($\lesssim 50^{o}$), resulting in many co → co relaxations. Gas discs of LTGs are more resilient to this and show less frequent misalignments.

What drives the long-lived misalignments?

- Long(er)-lived misalignments more common in galaxies with:
  - Lower star-forming gas fraction
  - More gas inflow post-formation (centrals)
  - Reside in more massive halos (centrals)

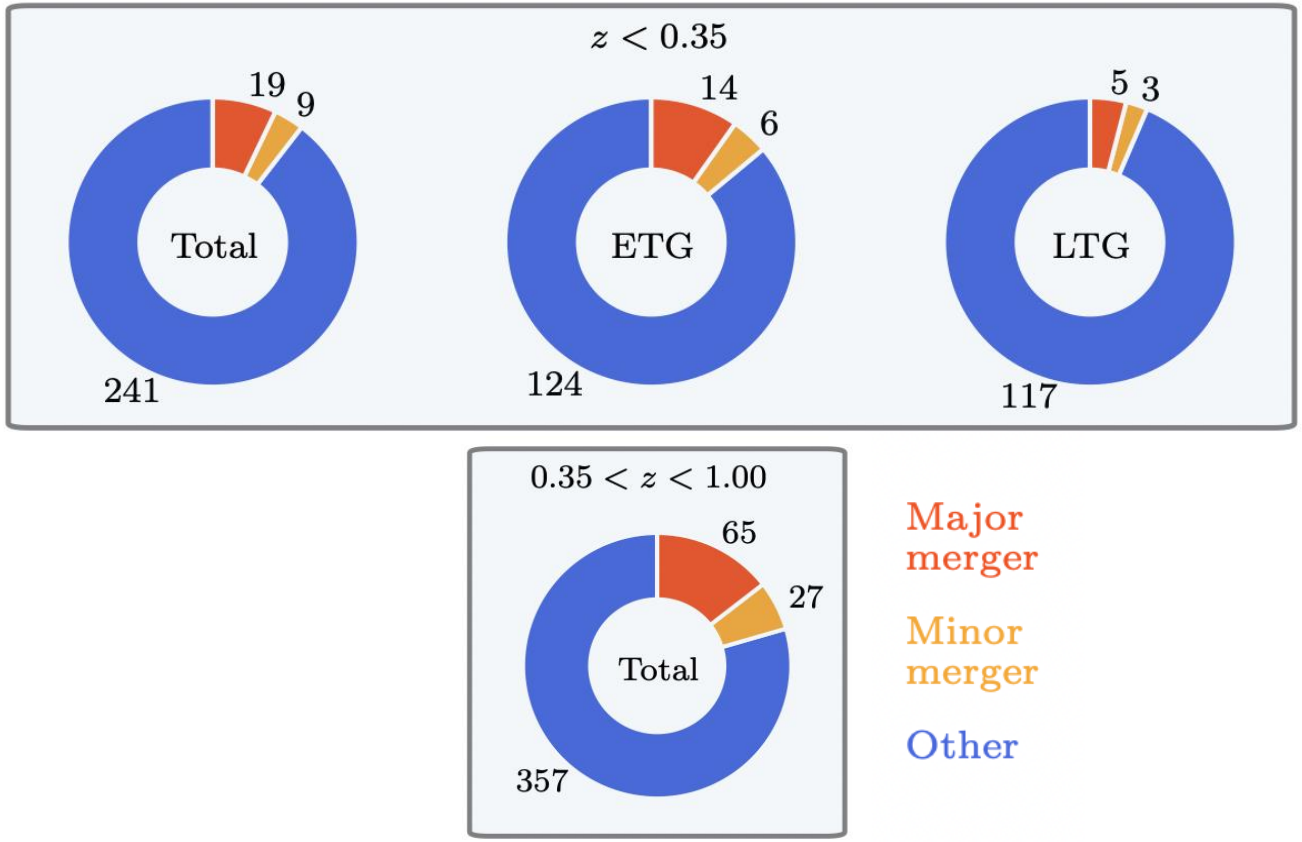
- What could explain these trends?
  - Less massive gas discs → more easily perturbed
  - More inflow → more misaligned smooth accretion?
  - More massive halos → more halo cooling from a misaligned halo?



Baker et al. (2025)

Incidence of mergers with misalignment formation

- Within $z < 0.35$, mergers coincide with only $\approx \mathbf{10\%}$ of unstable misalignment formation.
  - This holds true for stellar mass $> 10^{10}\,\mathrm{M}_{\odot}$
- Among ETGs, this is $\approx \mathbf{14\%}$.
- Major mergers are more effective than minor mergers at forming unstable misalignments.



Baker et al. (2025)

Incidence of mergers and unstable misalignments

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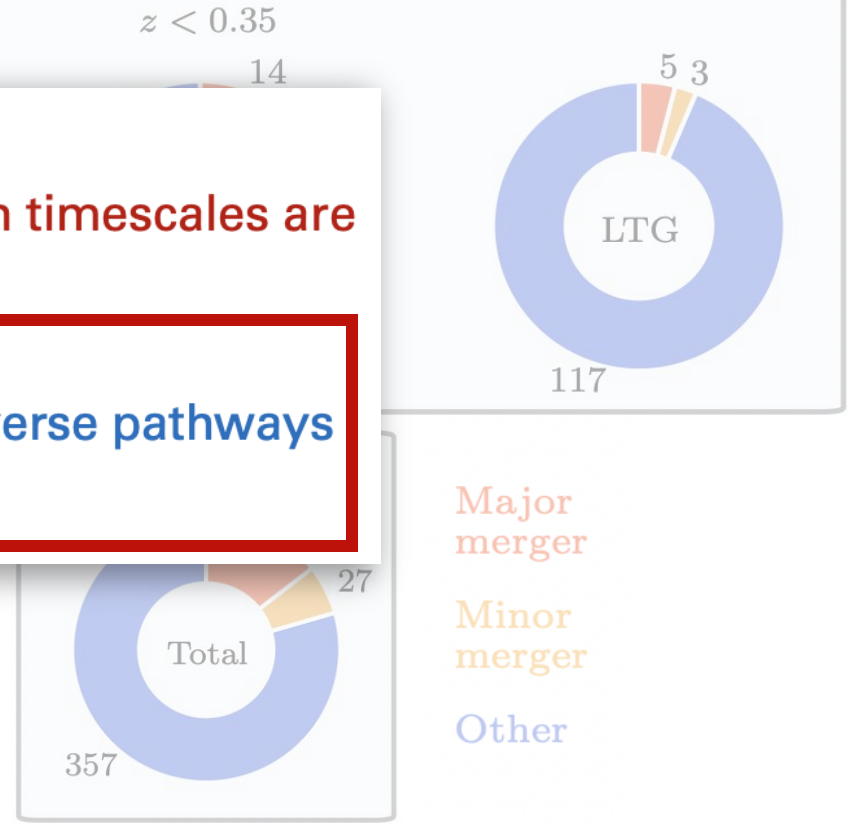
2 potential solutions:

1. Merger-driven misalignments, but relaxation timescales are much longer than theory predicts
2. Relaxation timescales are short but replenishment/formation occurs through diverse pathways (i.e. more frequent misalignments)



Baker et al. (2025)

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Summary from EAGLE:

- Misalignments tend to be short-lived and are described by a log-linear relationship.
  - Small population of long-lived misalignments does exist, but these are not dominant.
  - ETG misalignments occur frequently and displaced by small angles, resulting in many co → co relaxations. Gas discs of LTGs are more resilient to this.
  - **i.e. there is no dominant population of long-lived unstable misalignments in ETGs.**

- Misalignment timescales are enhanced in galaxies that have: lower star-forming gas fractions, higher gas inflow rate post-formation, and reside in more massive halos.
  - We attribute this to the susceptibility of relatively lower-mass gas discs to perturbations and halo cooling in more massive systems.

- Mergers do not dominate formation of misalignments.
  - **i.e. unstable misalignments form through diverse formation pathways suggesting cold-gas replenishment in ETGs does the same.**