AGN-Merger Connection in HST/JWST and simulated galaxies

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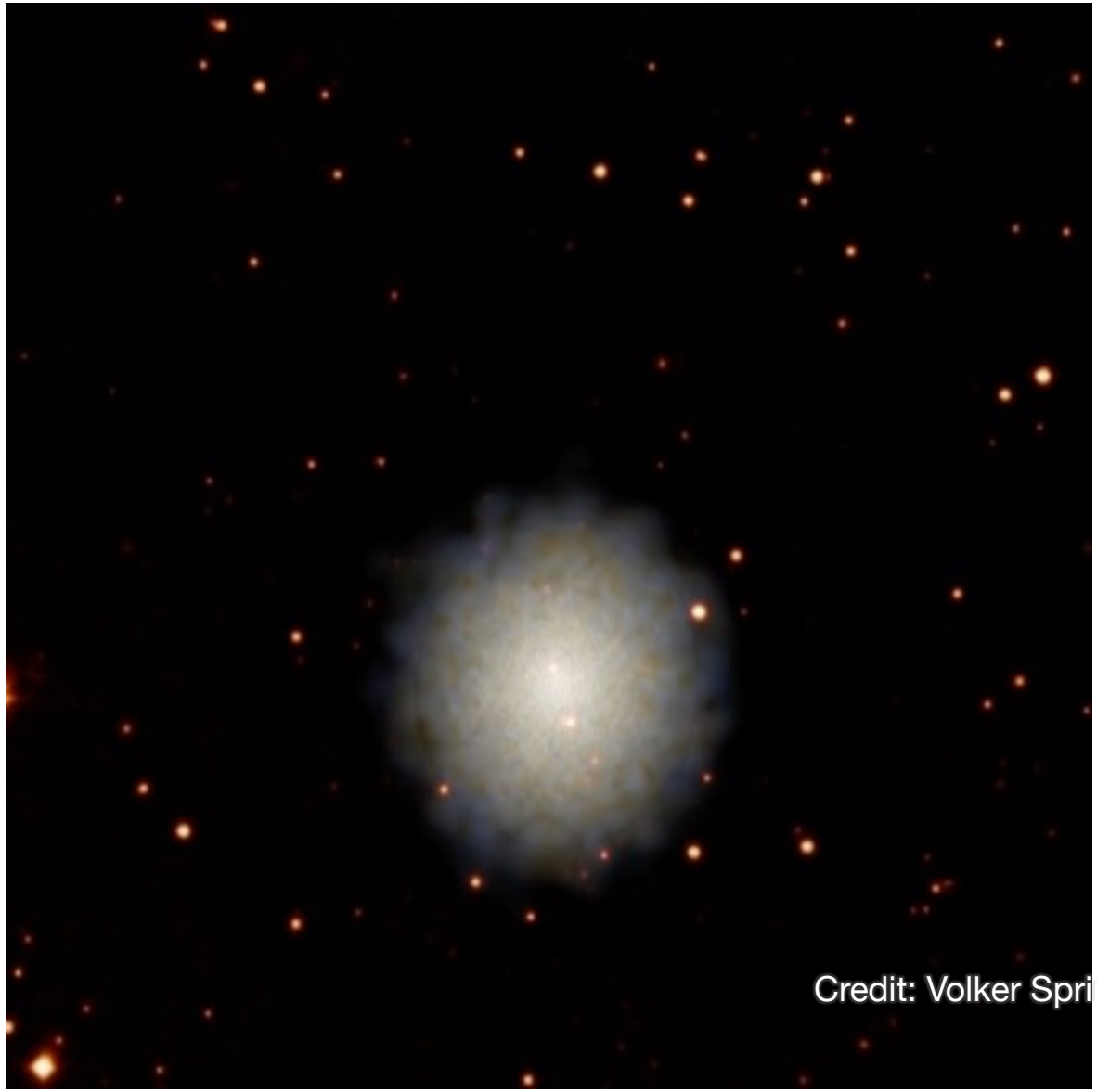
Survey Science Group Workshop 2024 – January 30th 2024

Artist concept of SMBH - Image credit: NASA/JPL-Caltech

"Galaxy Merger as a AGN trigger" scenario from *theory*

- Theory: Isolated, **idealized** simulation of galaxy merger. Springel+05, Hopkins+05,06
- Mergers can effectively dissipate angular momentum and funnel gas to the center growing both BH and bulge.
- It can easily explain the tight correlation between BH and bulge.

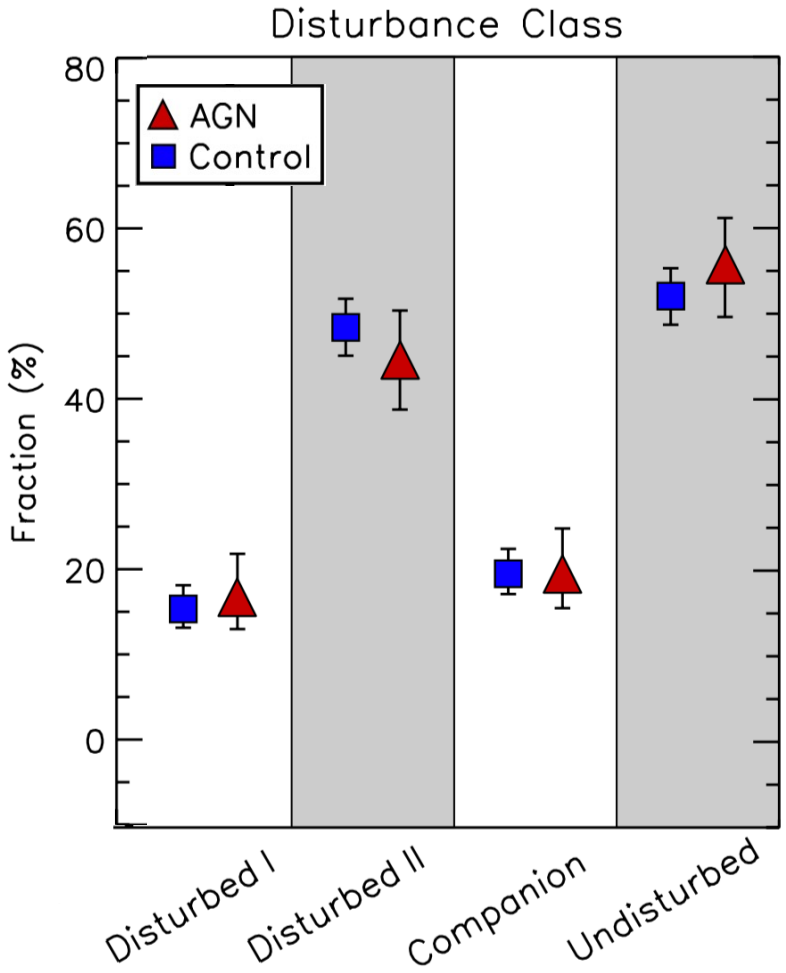


The elusive AGN-Merger connection from *observations*

- Are AGN more common in mergers?

	Low-z	High-z
YES!!	Koss+10, Koss+18 Ellison+19 Gao+20	Donley+18 Goudling+18
NO!!		Pierce+07 Georgakakis+09 Cisterrnas+11 Kocevski+12 Villforth+17 Marian+19 Schawinski+11

- Elusive AGN-Merger connection from observations
- Depending on the method to define a merger, we can get different conclusions on the merger-AGN connection -> ***Let's select mergers in the same way as observers do!***



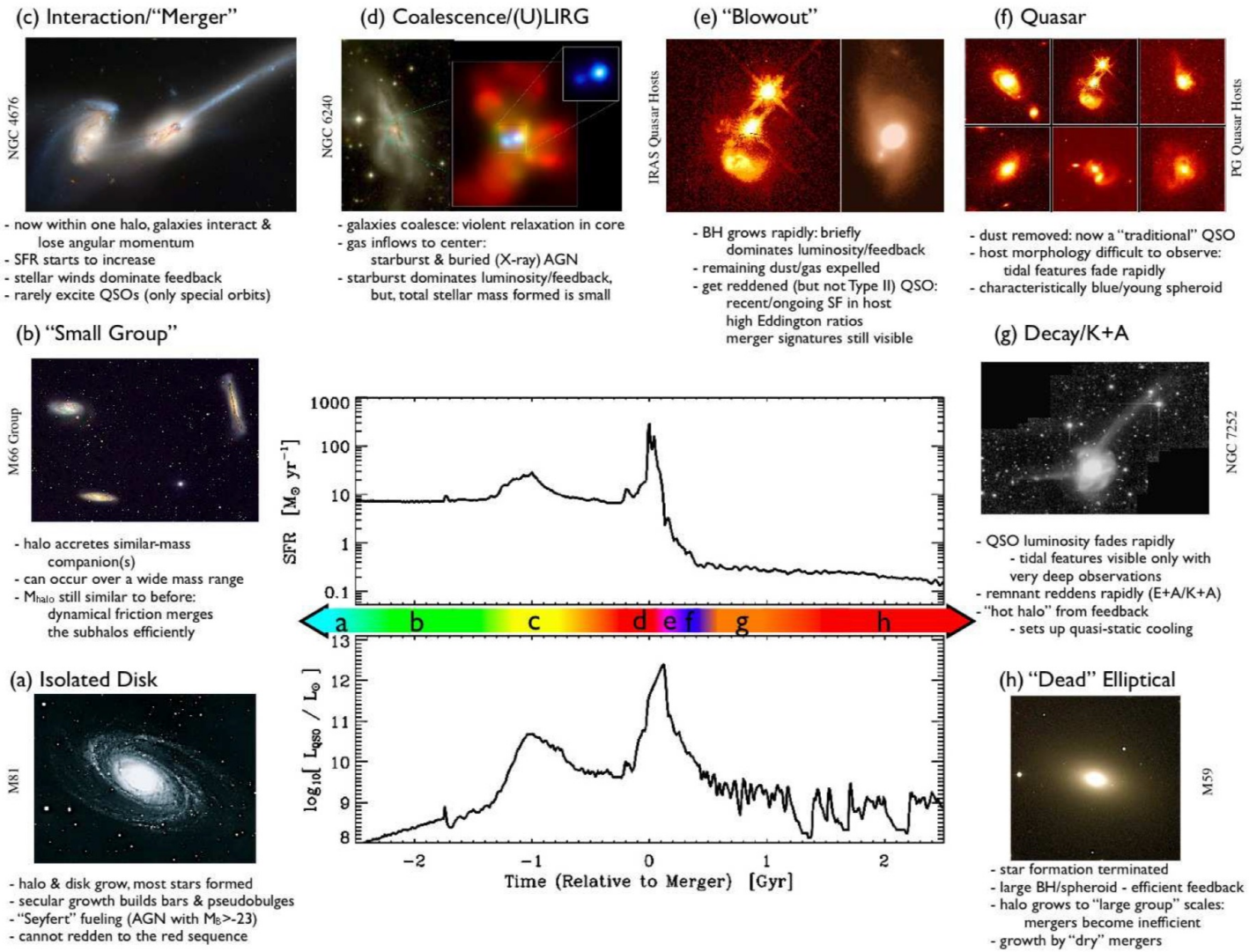
CANDELS at z~2; *Kocevski et al. 2012*

Does the simulation really predict that an AGN-merger connection will be 'observed'?

“The connection between mergers and AGN activity in simulated and observed massive galaxies”
Sharma, EC et al. 2024, MNRAS, 527, 9461

Problem (1) : prediction was from the *idealized* simulation

- **Idealized major merger simulation of two gas-rich disk galaxies**
- **We need to test this "galaxy merger as a AGN trigger" scenario with cosmological simulations** that include complex conditions in the high-redshift universe (**multiple mergers, cosmological infall, internally unstable galaxies**).



Problem (2) : Sequence vs. Capturing the moment

- Merger simulations : show the whole sequence of galaxy & BH evolution
- Observations: only capture the “moment” of merging sequences (or AGN activities)





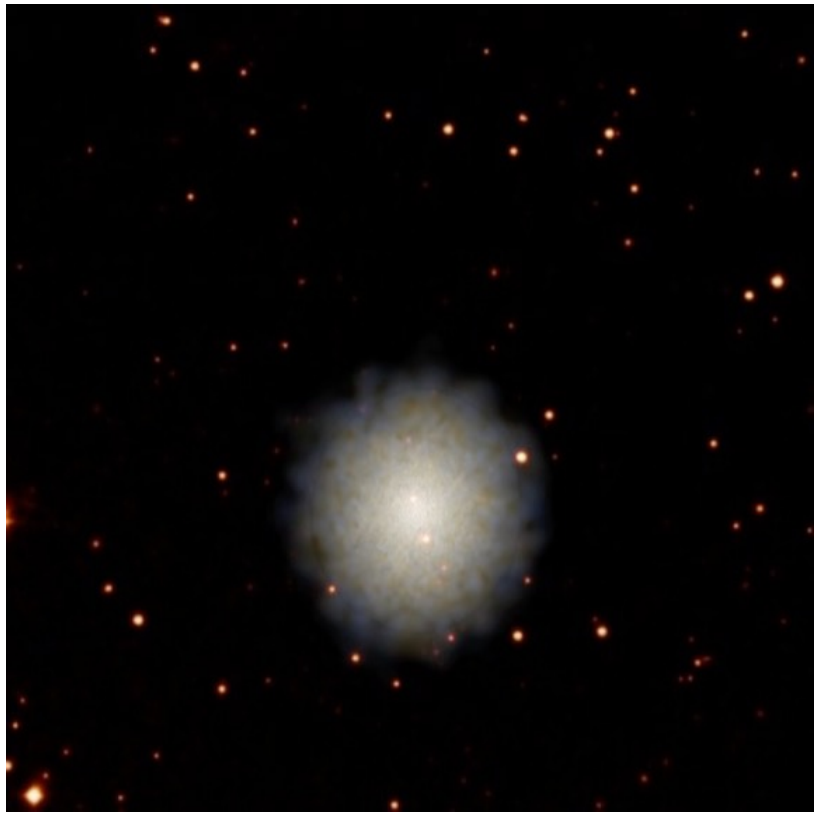
Close



Open

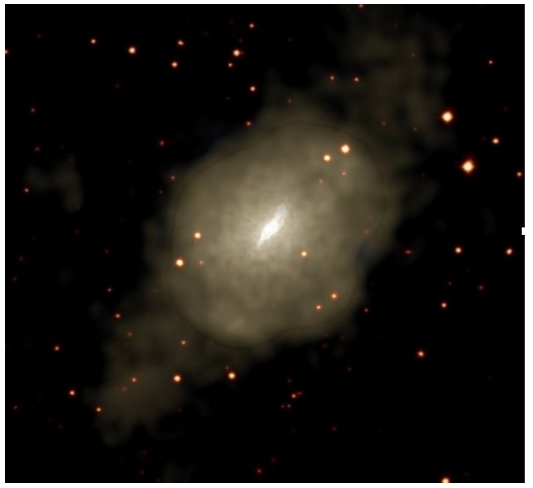
Problem (2) : Sequence vs. Capturing the moment

- Merger simulations : show the whole sequence of galaxy & BH evolution
- Observations: only capture the “moment” of merging sequences (or AGN activities)





Merger!



Merger?

Problem (3) : Various “merger” definitions

- Depending on the method to define a merger (and AGN), we can get different conclusions on the merger-AGN connection.
- Merger/morphology classification methods:
  - **Simulations: Halo finder traced “companion/merging” galaxies**
  - **Observation: Human visual classification (e.g. Kocevski+12)**
  - **Quantitative morphology classification using G-M_{20} (e.g. Lotz+04)**
- Selecting mergers in the same way as observers do is important.
  - **Need to generate noise-added synthetic images from simulations**

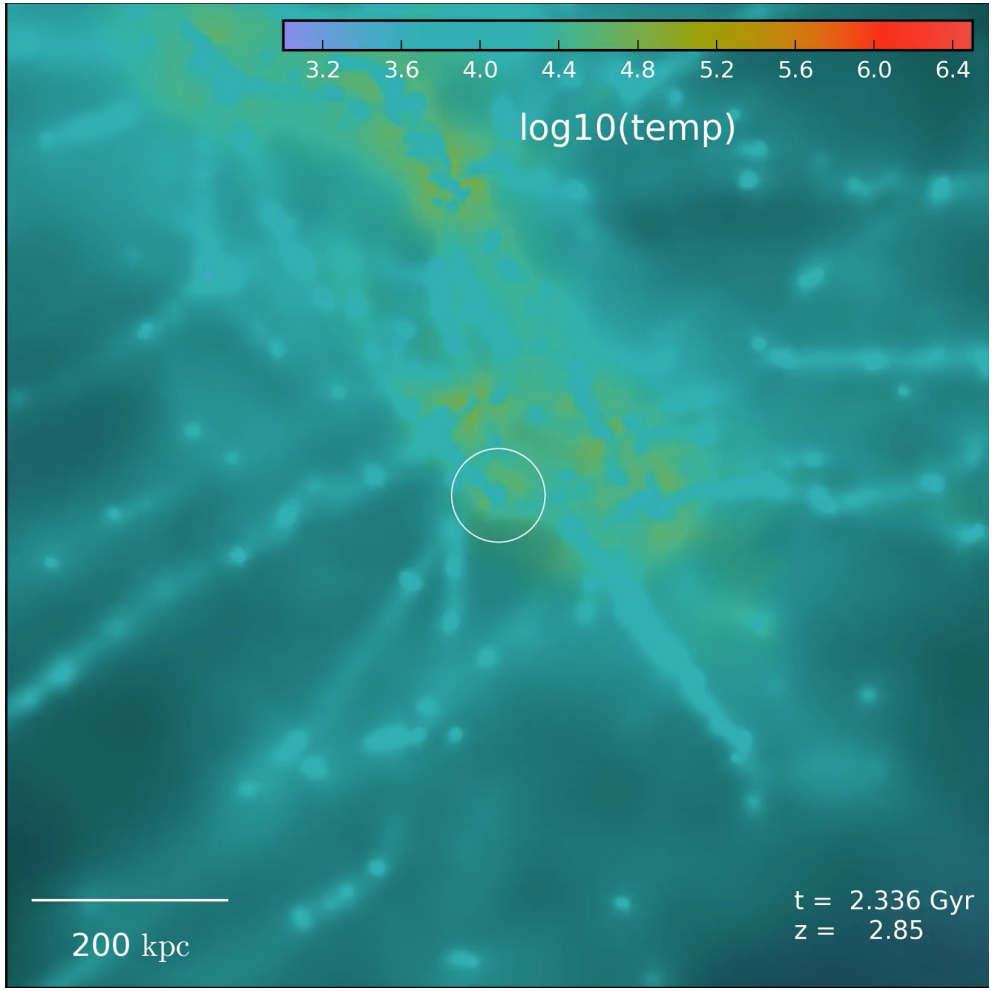




Method (1) : Cosmological simulations of galaxies

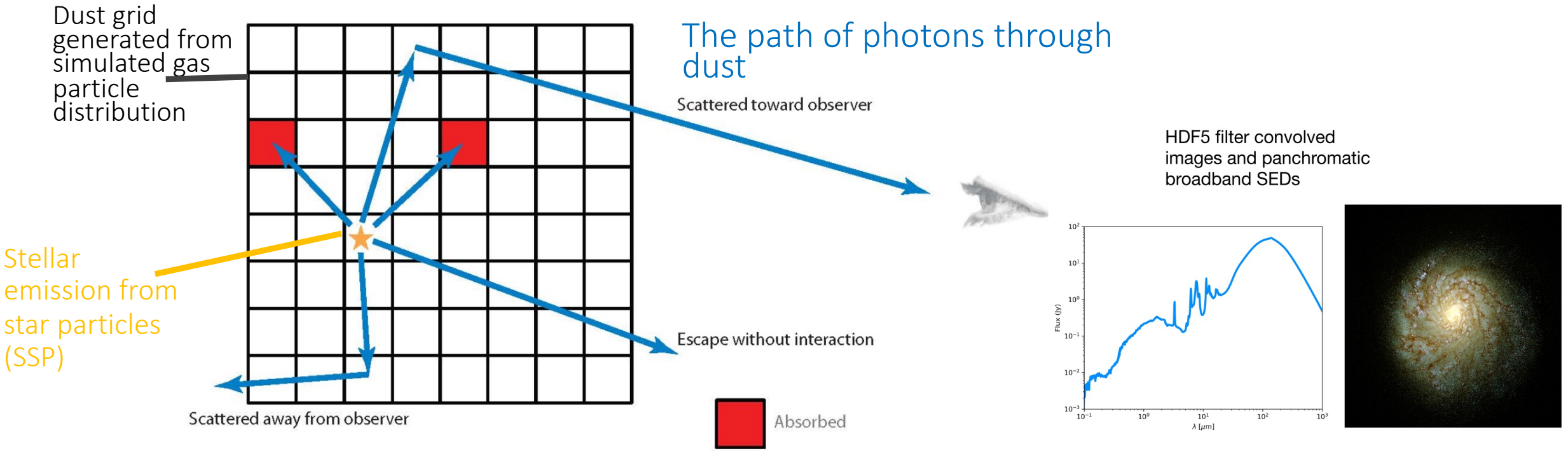
- **30 Cosmological zoom-in simulations**: Central galaxies with z=0 mass Mstel=10^{11} - 10^{12} M_{sun} Choi+17
- **GADGET-3 Smoothed particle hydrodynamic simulations**
- **Used snapshots 0.5 < z < 3.0**
- **Momentum feedback from AGN** (1. Winds and 2. Radiative heating/momentum) Choi+12/14/15
- SN wind feedback, Feedback from massive stars ('Early' feedback), AGB winds Núñez+17
- Metal enrichment and metal line cooling Aumer+13 / Modified SPH (SPHGal) Hu+15

Choi+17



Method (2) : Mock Observations via radiation transfer

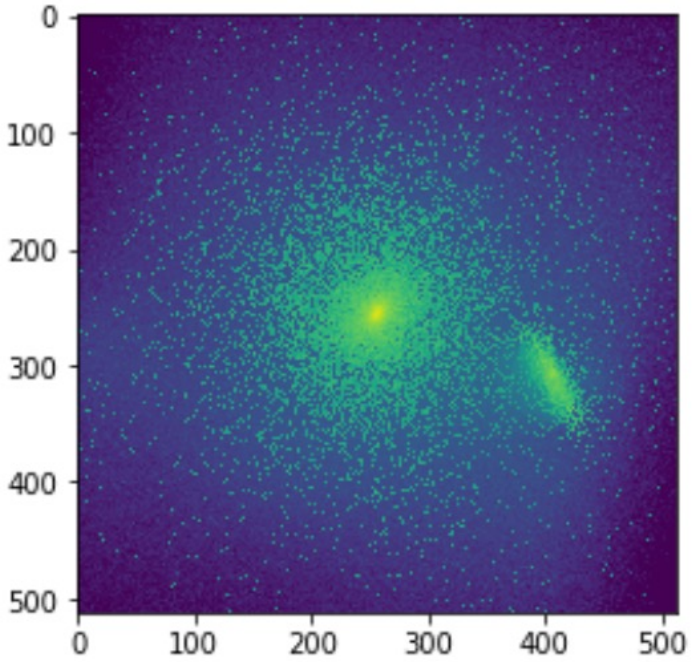
- Bridge the divide between simulations and observations.
- "**Powderday**": a dust radiative transfer package (Narayanan et al. 2021, ApJS, 252, 12)
- 12,000 HST-WFC3 F160W galaxy images with a CANDELS pixel scale at 0.5<z<3

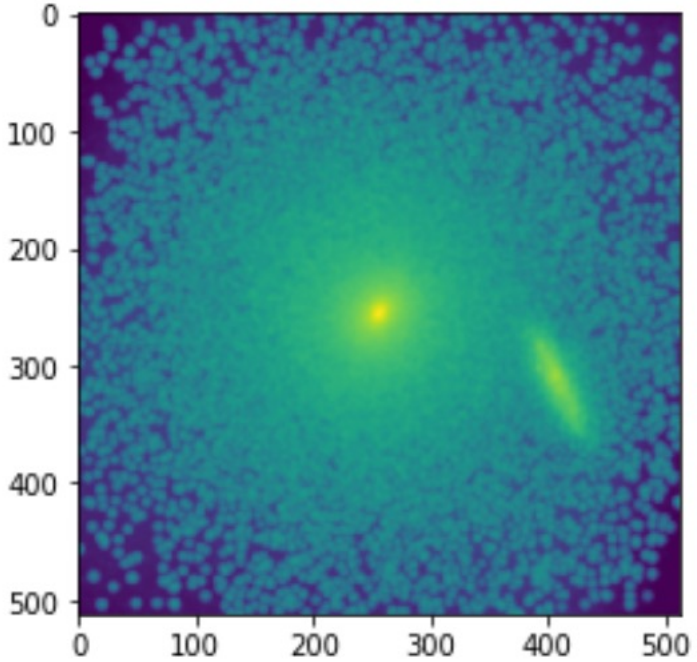


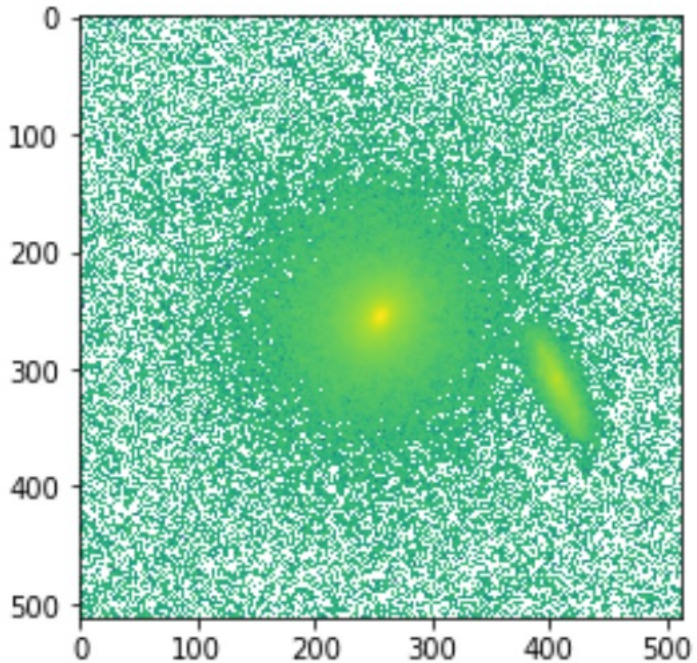
- Any filter images can be generated with radiation transfer runs from UV to sub-mm.

Method (3) : Mock Observations - CANDELIZATION

- **12,000** HST-WFC3 F160W images with a CANDELS pixel scale, PSF, and noise.
- A direct prediction for how our simulated galaxies would appear in CANDELS survey
- Morphological measurements on mock images (Gini, M20, concentration, Asymmetry)







Sharma, EC et al. 2024

Merger definition with mock images

- 12,000 images with intrinsic merger information (from merger tree) attached
- We want to classify mergers in observed images and simulated mock images in **exactly the same way**.

	Simulation	**Observation**
Usual merger classification method	Intrinsic (Merger tree based)	Visual inspection
New merger classification method with mock images	Visual inspection (work in progress)	**ML trained Intrinsic merger classification**

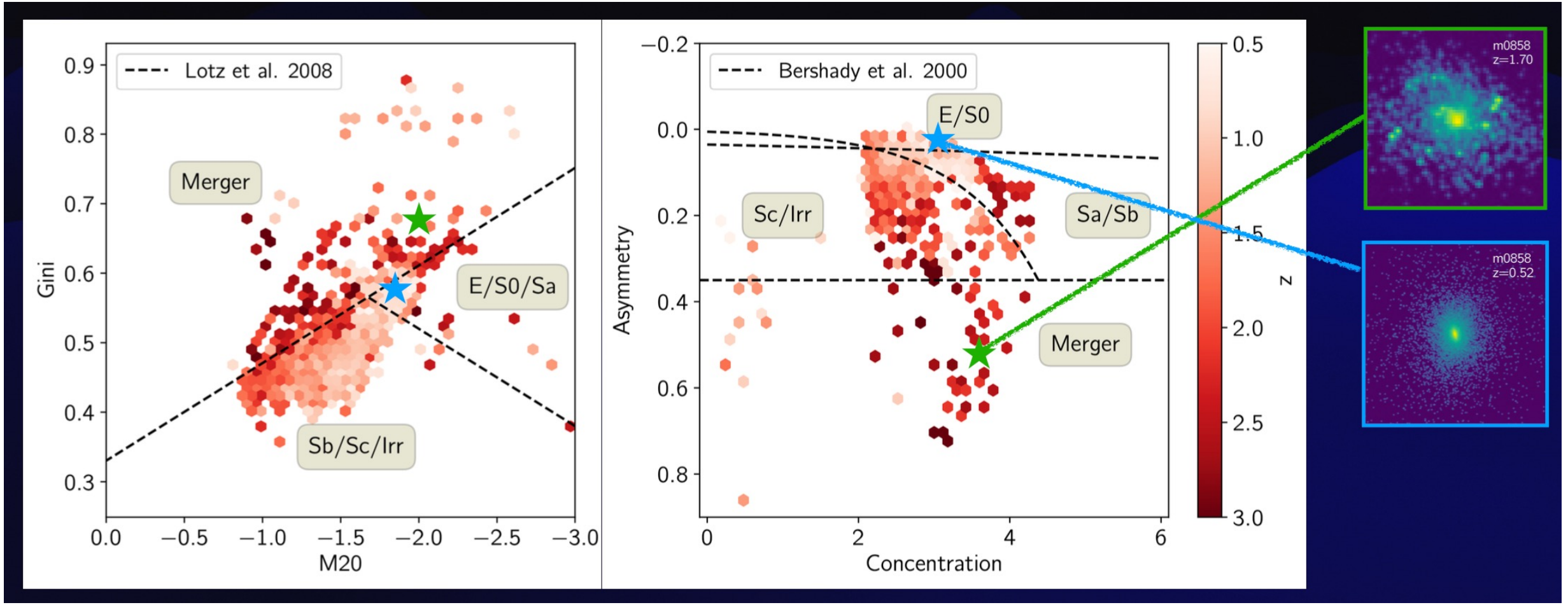
Morphological parameters

- Merger detection using non-parametric parameters (statmorph)



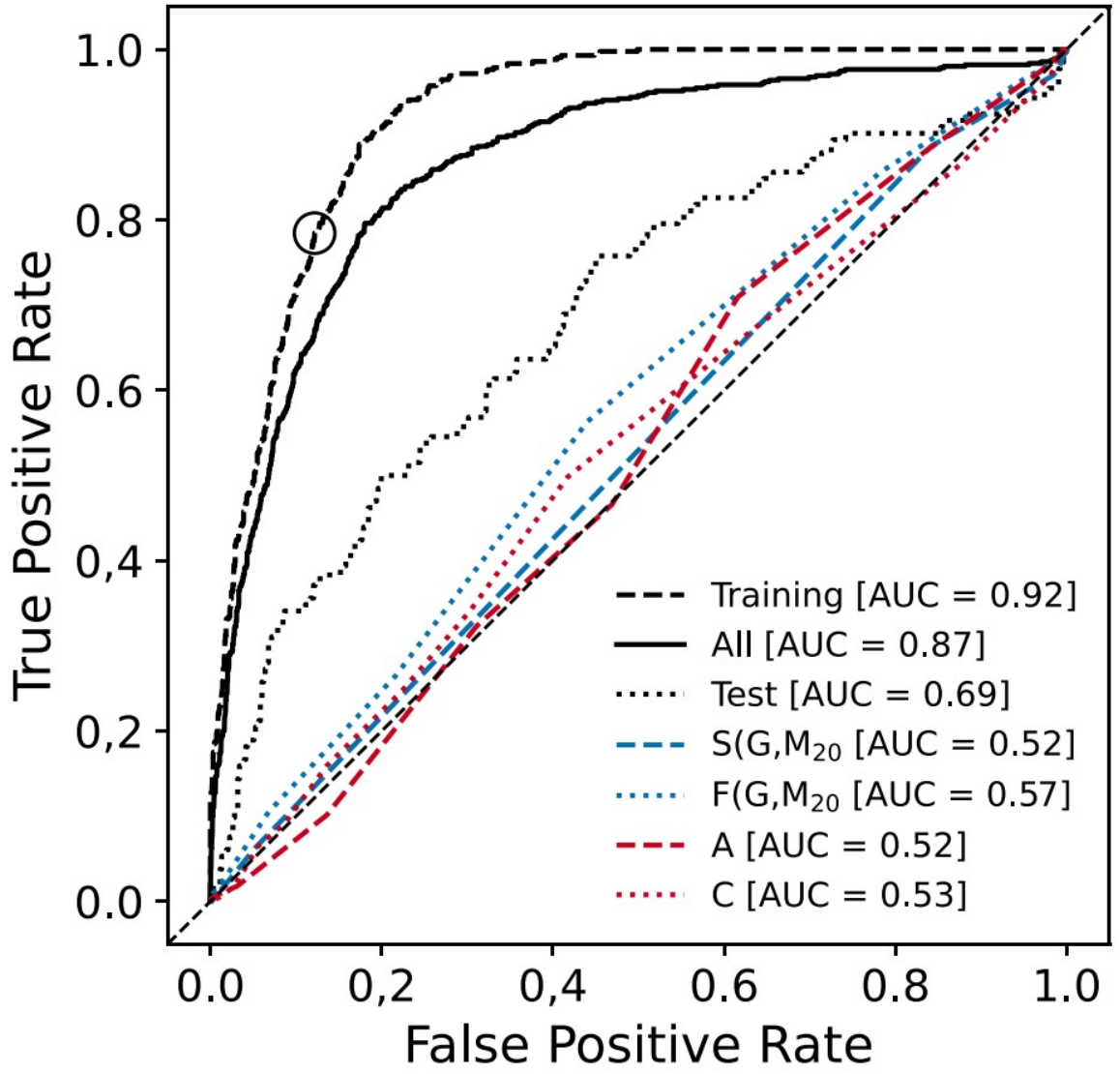
Non-parametric morpological parameters

- Gini, M_{20}, Asymmetry, Concentration



Machine learning trained Merger classifier

- G, M_{20}, A, C for features (inputs)
- Instrinsic (merger-tree) merger definition for label (output)
- Random forest classifier for merger vs. non-merger
- Trained over 12,000 simulated mock images
- RF classifier trained over mock images is applied to both mock & observed CANDELS images (HST-WFC3 F160W images).



Sharma, EC et al. 2024

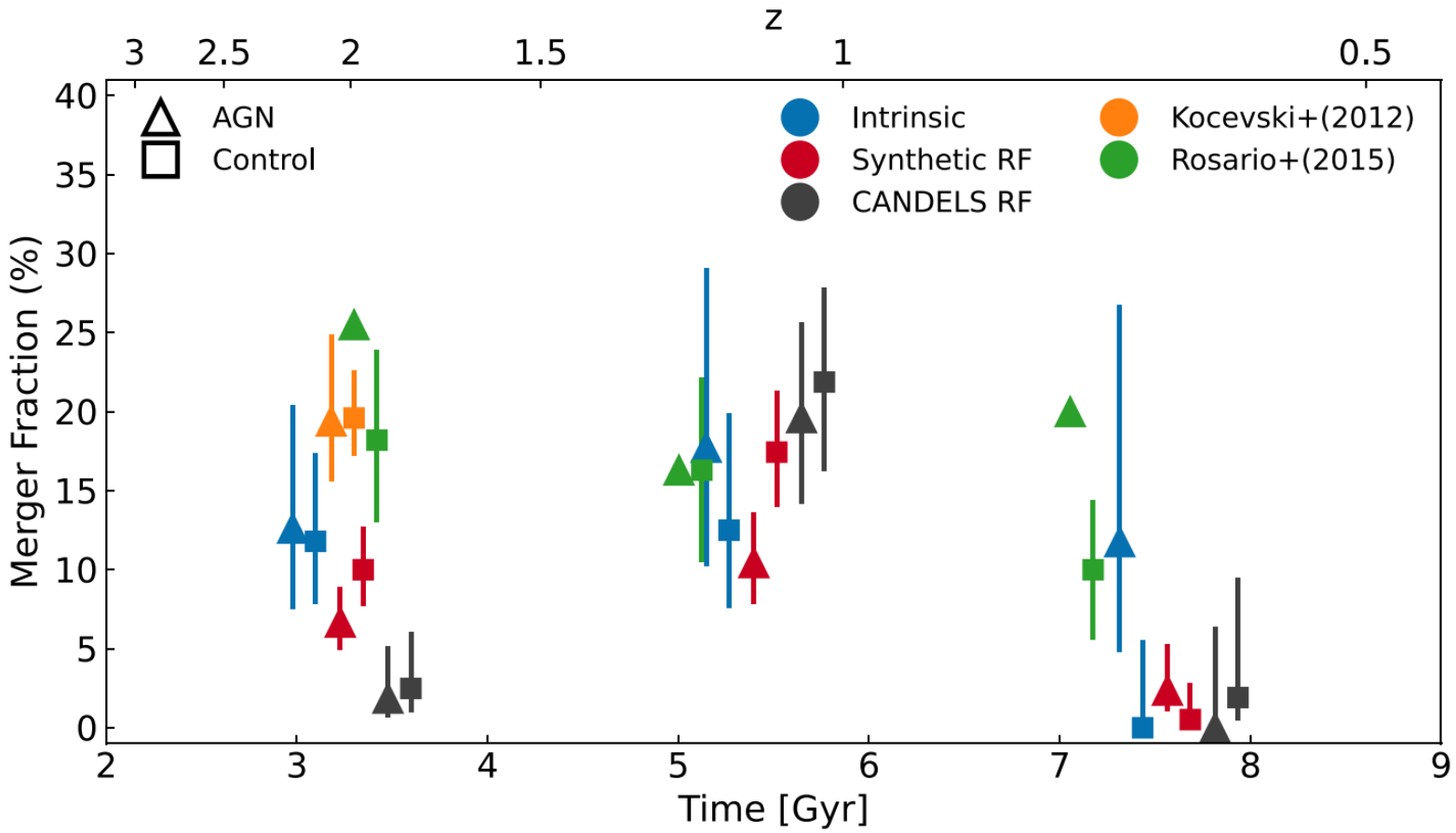
Merger fraction of AGN & control inactive galaxy sample

Simulation:

Intrinsic merger

RF classifications applied to synthetic images

RF classifications applied to CANDELS observed images



Observation:

Visual inspected mergers for observed CANDELS galaxies

Kocevski: "companions" pair fraction

Rosario: the interaction fraction

The AGN samples do not exhibit a consistent, statistically significant excess in merger fraction regardless of how the mergers are identified.

Sharma, EC et al. 2024

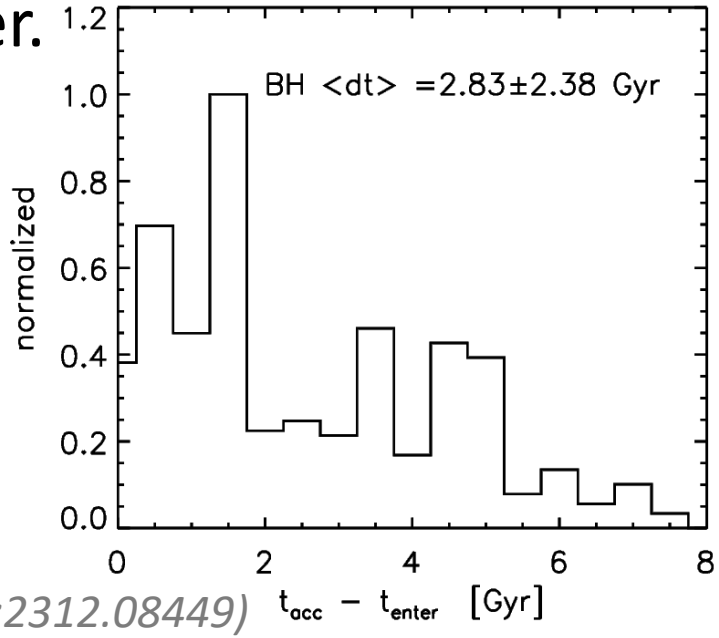
AGN do not appear to...

Sharma, EC et al. 2024

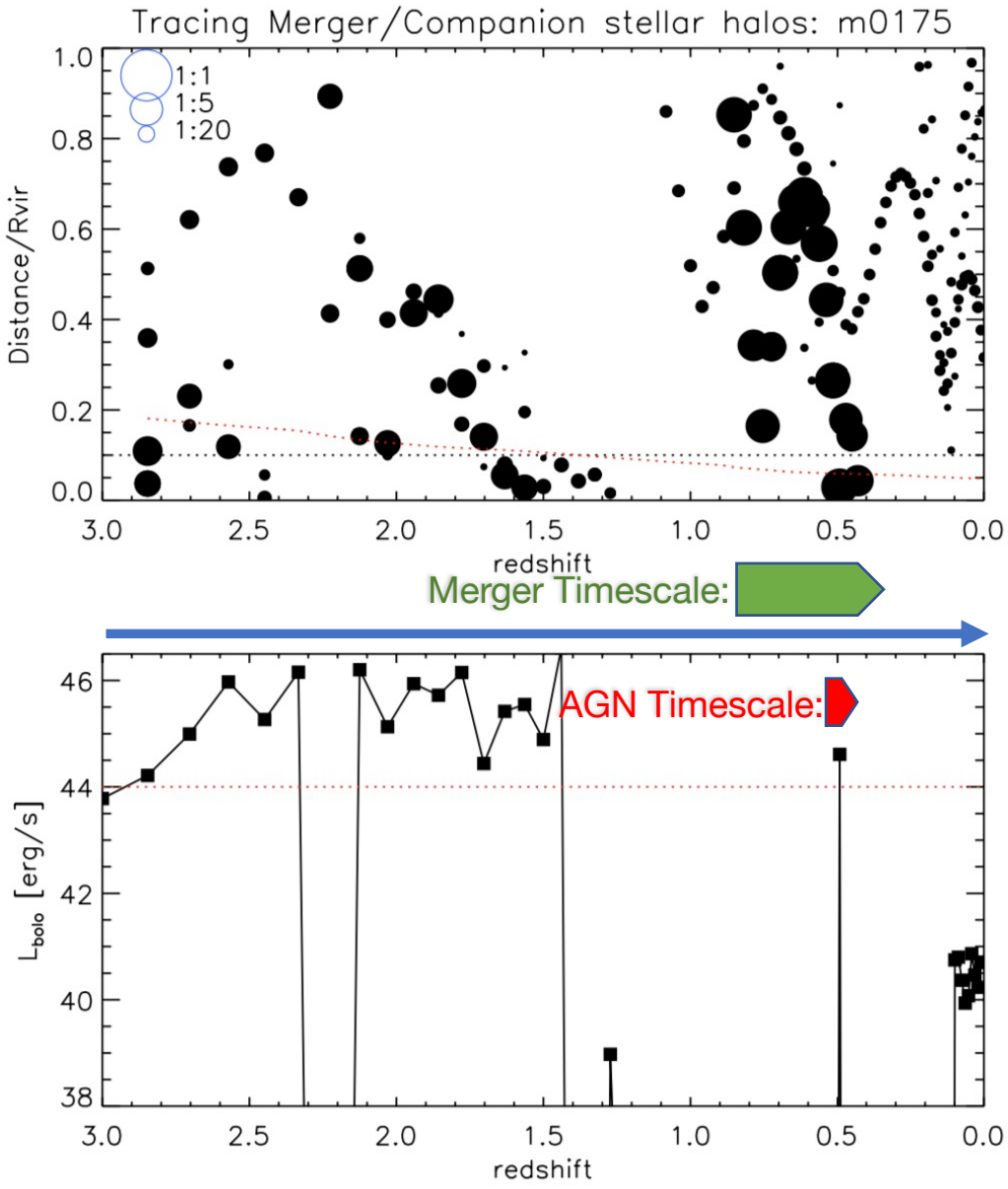
- live in merging systems, because..

1. There is a significant time-lag between merging and AGN triggering.

2. Merger is not the primary fueling mechanism – not all AGNs are triggered by merger.



Choi et al. 2024 (arXiv:2312.08449)



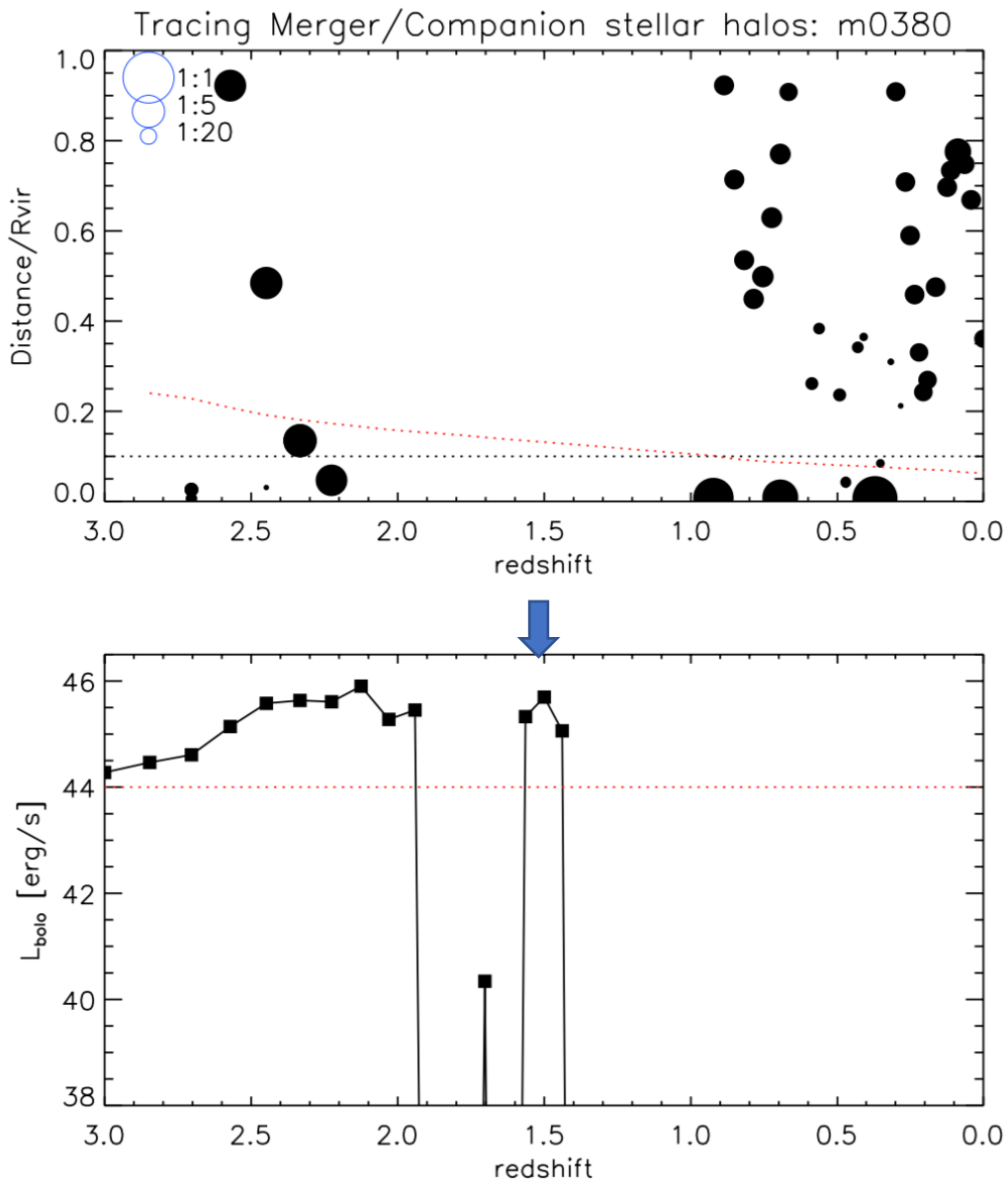
AGN do not appear to...

Sharma, EC et al. 2024

- ..live in merging systems, because..

1. There is a significant time-lag between merging and AGN triggering.

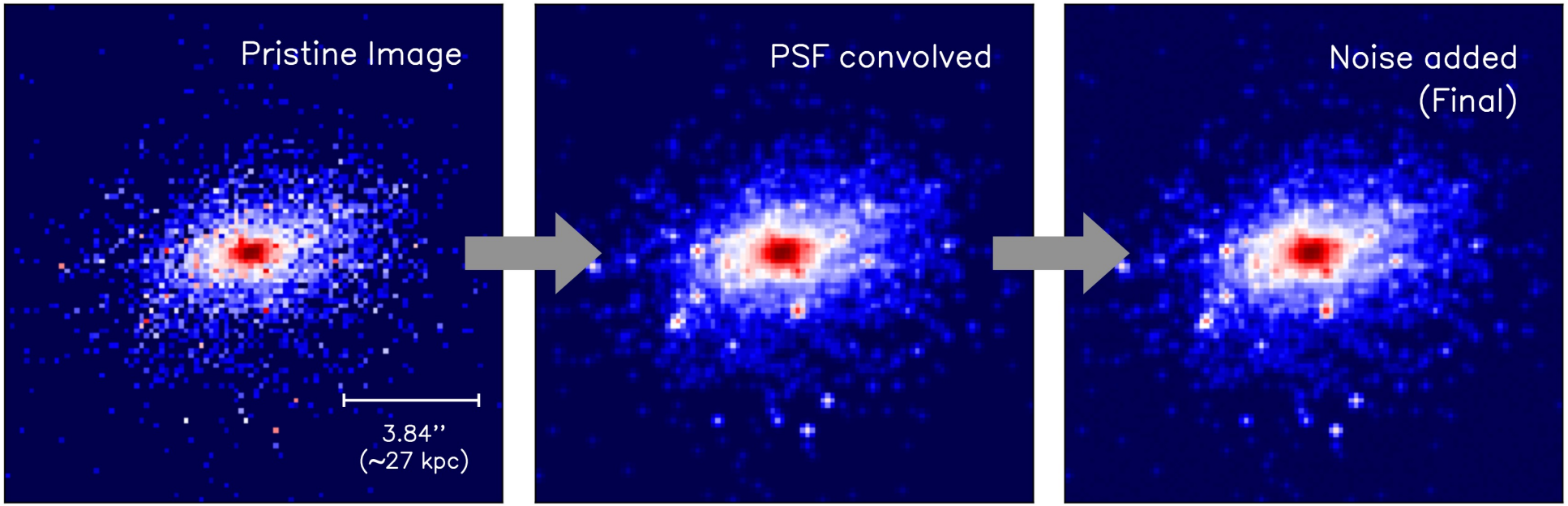
2. Merger is not the primary fueling mechanism – not all AGNs are triggered by merger. Secular processes can be dominant at high-z.



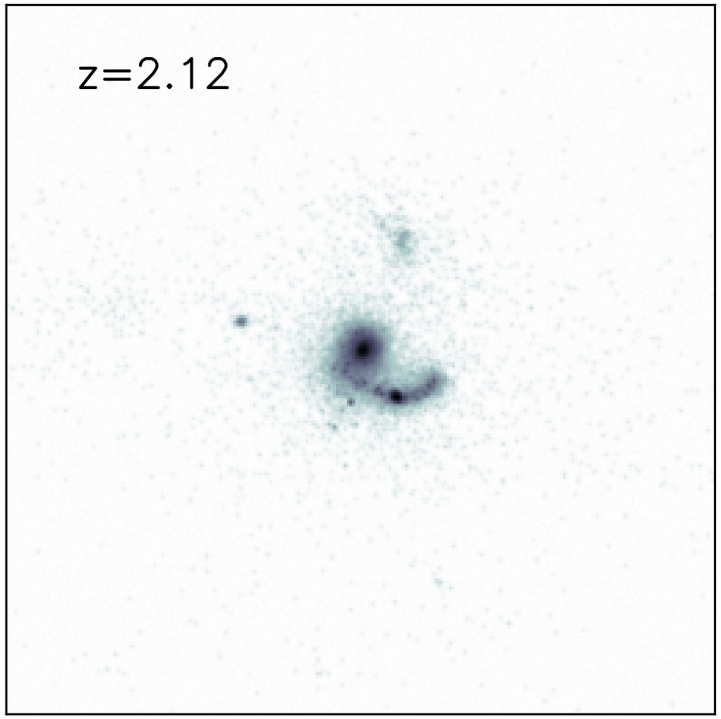
What about in JWST?

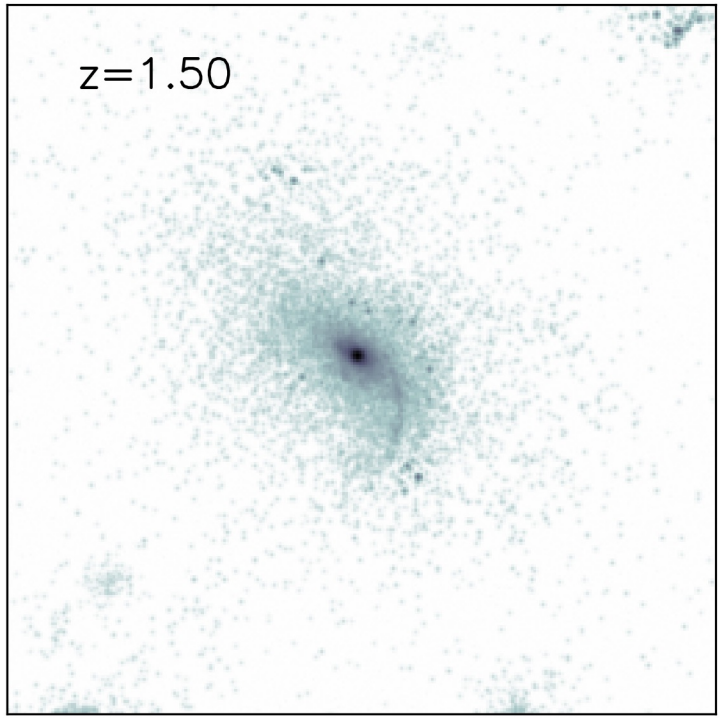
- **Can JWST observations detect the "AGN-Merger" connection?**

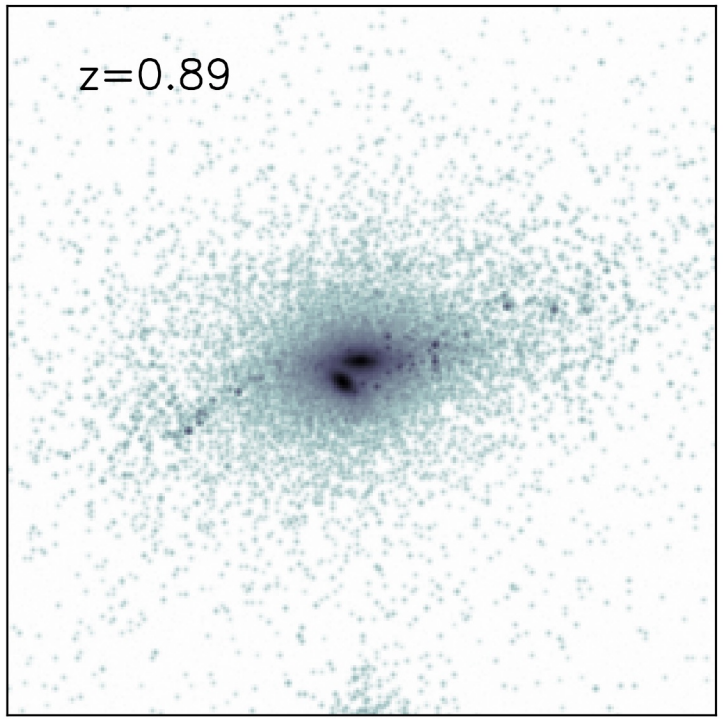
Filter	Angular resolution	FWHM of PSF	5σ SB limit
NIRCam F277W	0.03''	0.092''	29.2



What about in JWST? – sample images







- ~4000 JWST F277W images post-processed by Hannah Jhee

Visual inspection

- 2022/02/16 : 이명균 교수님 comment

  “ visual inspection 으로 모든 이미지를 merger define하면 재밌겠다!”

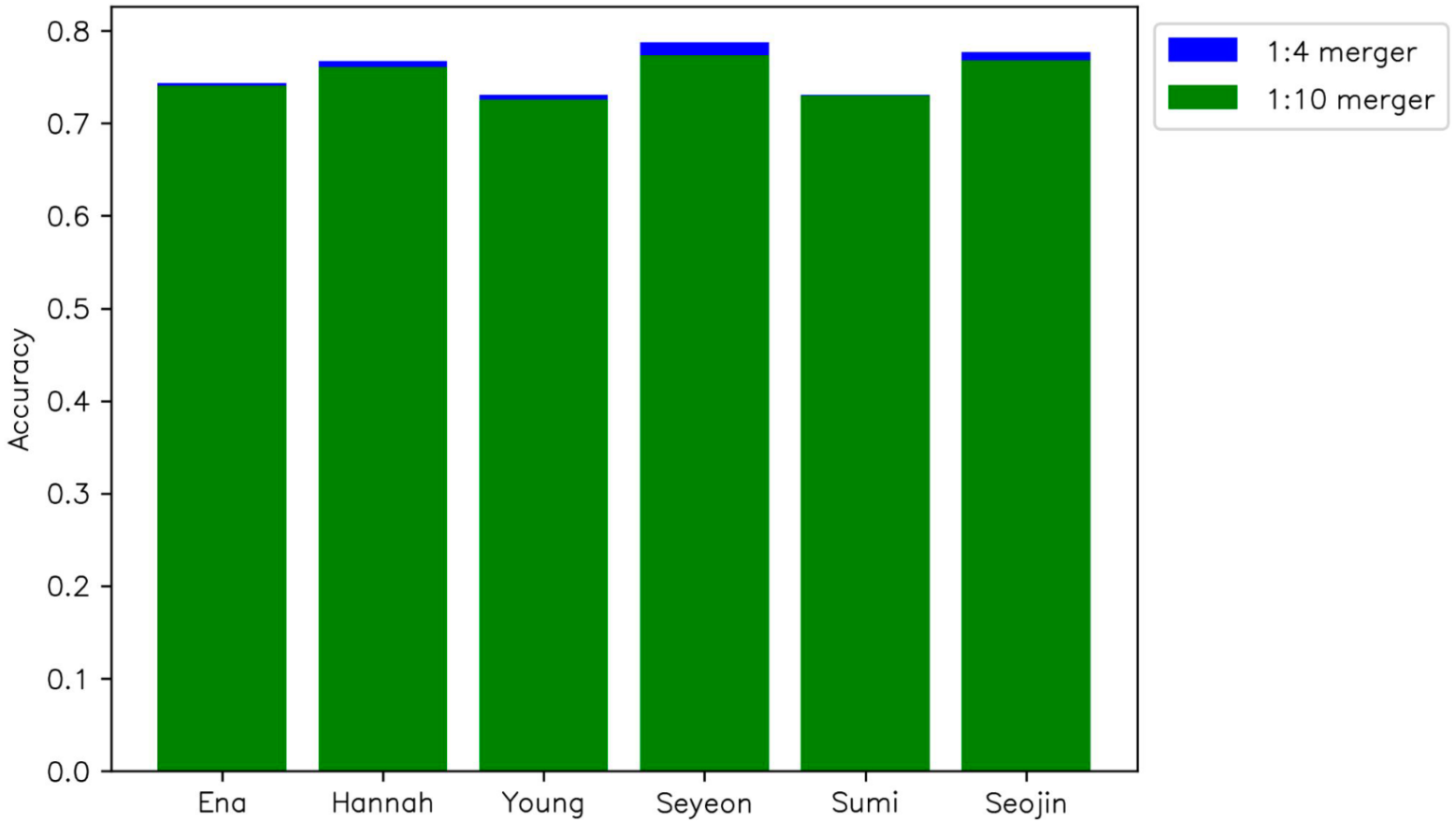
  -> So we did!

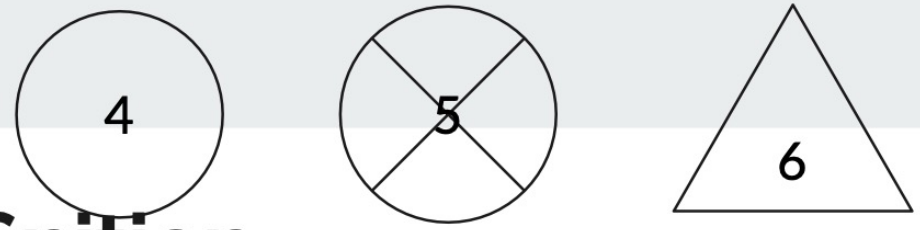


- 2024/01/22 (10 AM – 4 PM)

Visual inspection result

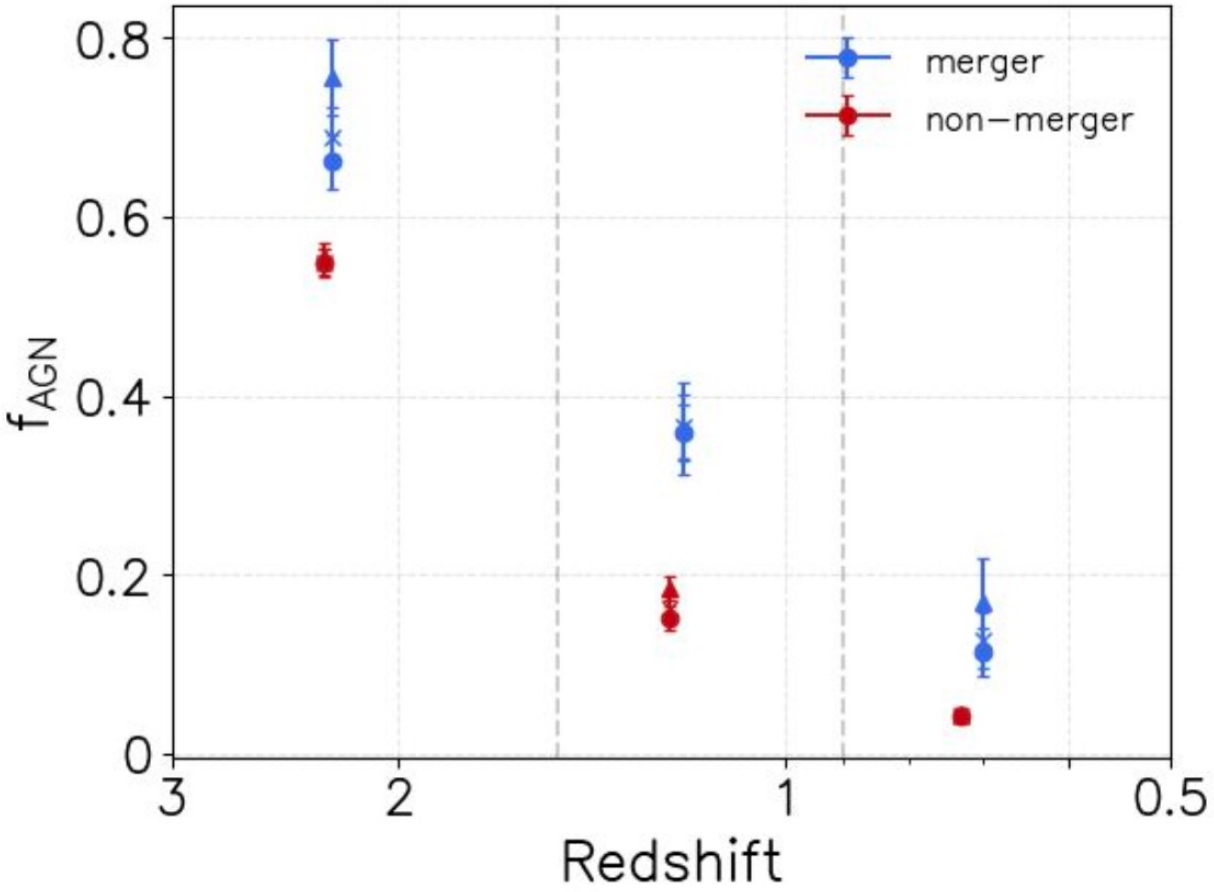
Result of Visual Inspection

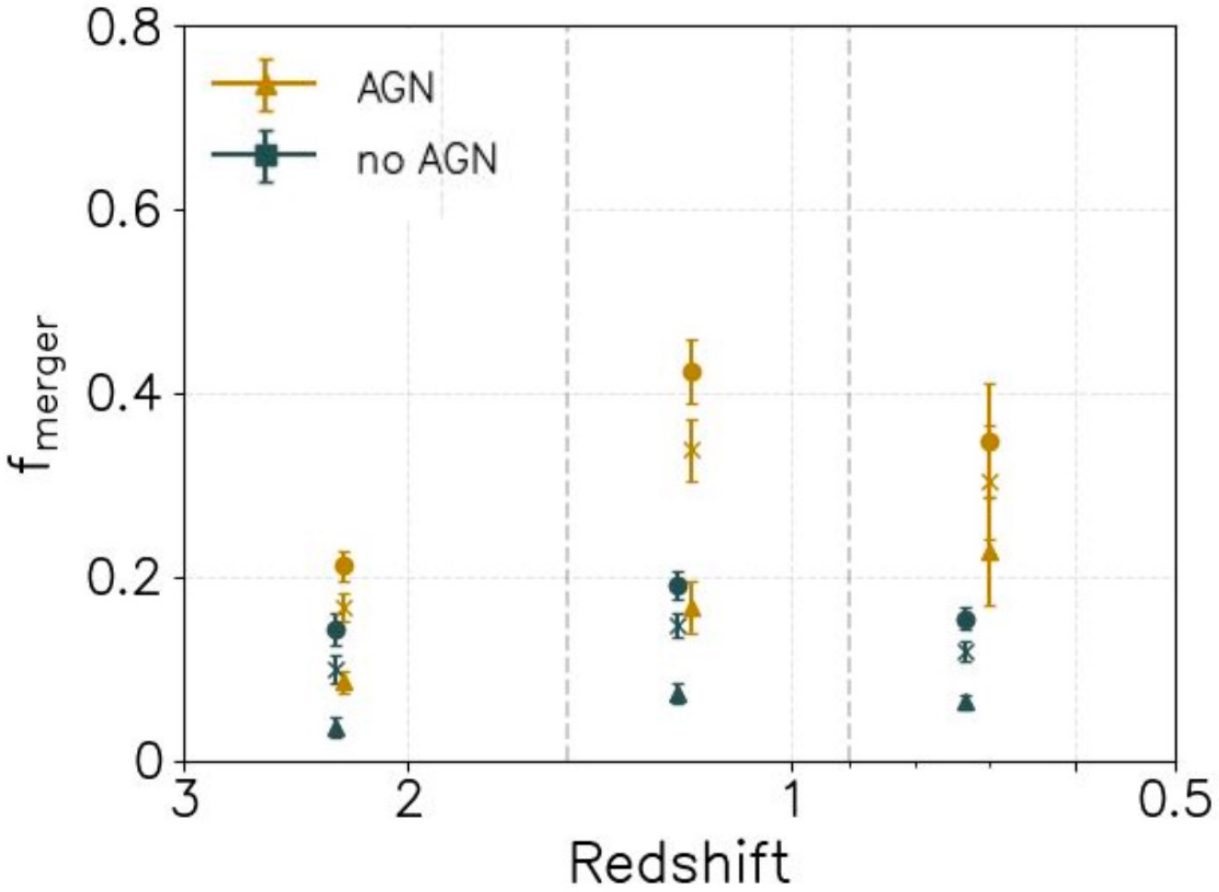




Synthetic Merger + new AGN definition

PRELIMINARY





Summary

- **The AGN-Merger connection was re-evaluated through cosmological simulations.**
- To bridge the gap between observation and theory, we generated **mock images** using post-processing techniques to enable merger identification, mirroring observational methods.
- Mock images were specifically crafted for **HST F160W** and **JWST F277W**, incorporating essential elements such as PSF, background noise, etc.
- Using intrinsic merger definition from the merger tree as “target (output)” and the morphological parameters of the mock image as “features (input)”, we employed a **random forest (RF) merger classifier** using machine learning techniques to distinguish mergers.
- The application of this RF classifier revealed no significant difference in the merger fraction between the AGN sample and the non-merger control sample, both in the mock HST images and in the HST CANDELS images.
- However, upon visual examination of the JWST mock images, the merger fraction of the AGN sample appeared slightly higher than that of the control sample. We are currently conducting a thorough analysis to understand the reasons behind this results.