Double yolk galaxies: late-stage galaxy mergers in COSMOS

Claire Lackner

Kavli IPMU (WPI)
University of Tokyo

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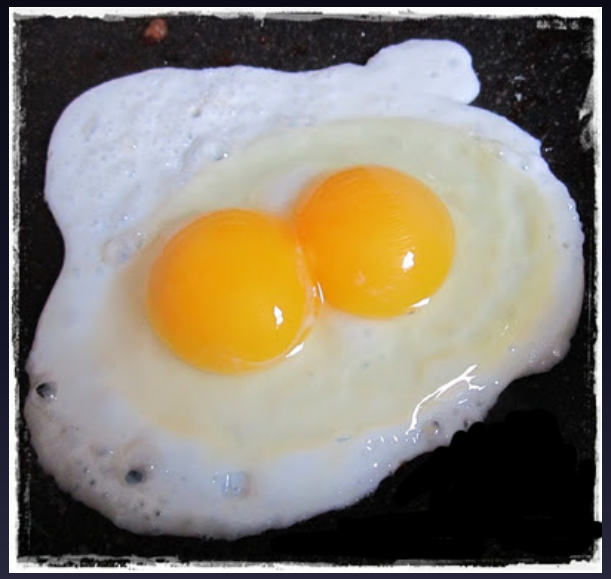
Introduction

1. Finding late-stage mergers
   - Median filtering
   - Sample from COSMOS
2. Properties of late-stage mergers
   - Merger rates
   - AGN fraction
   - Star formation rates



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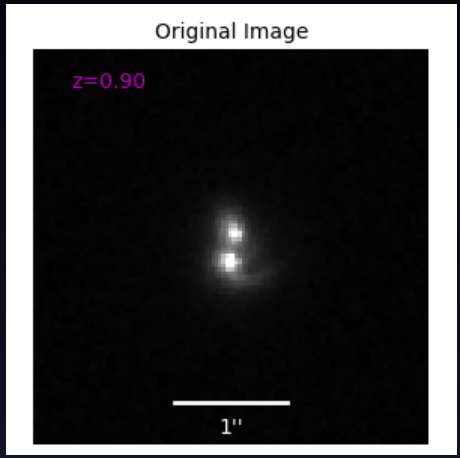
Median Ring Filtering Detection Algorithm



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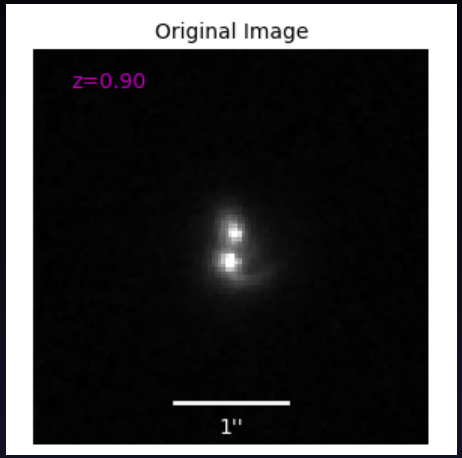

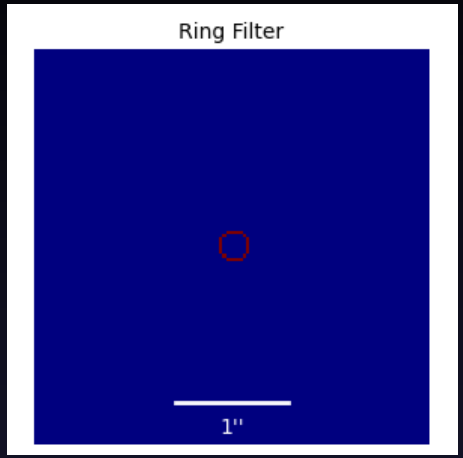

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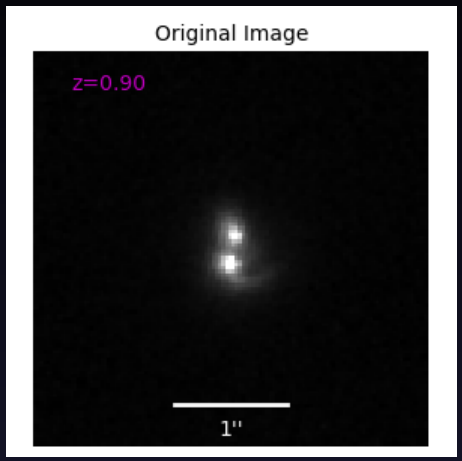

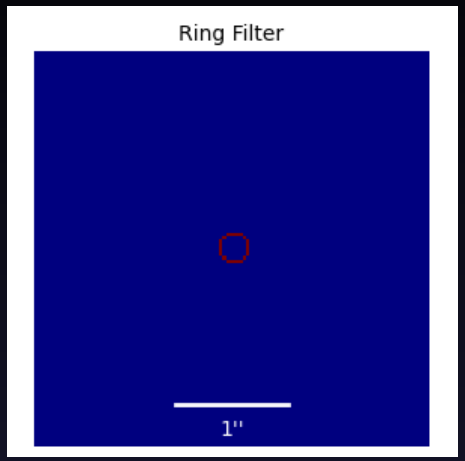

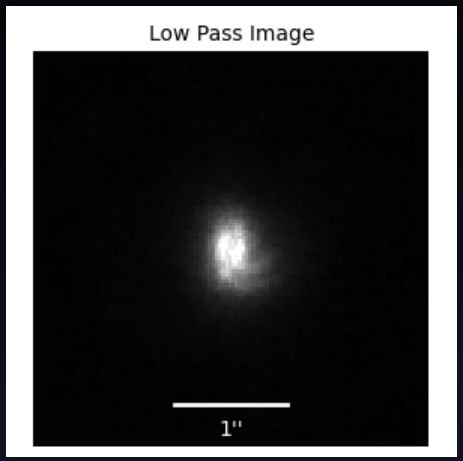

Median ring filter smooths on scales $< 1.3\times$ PSF FWHM.
Peaks are distinguishable in difference image.

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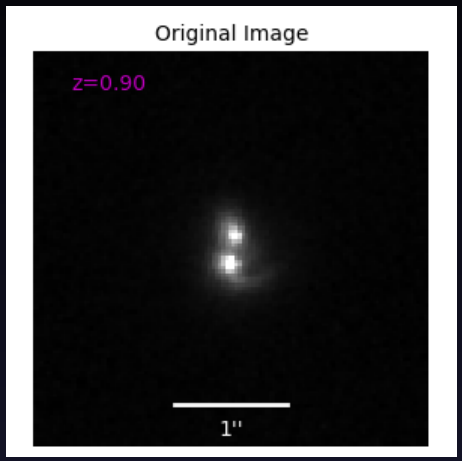

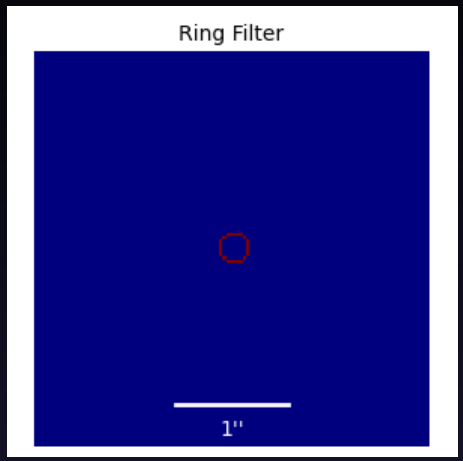

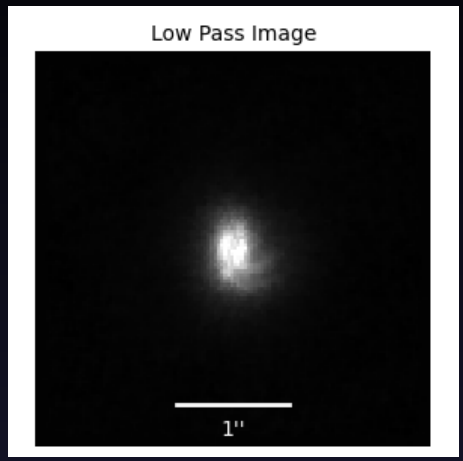

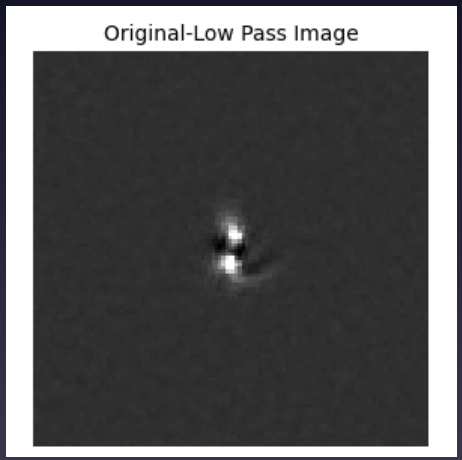

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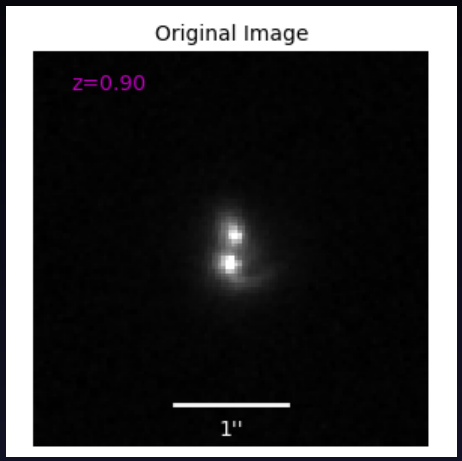

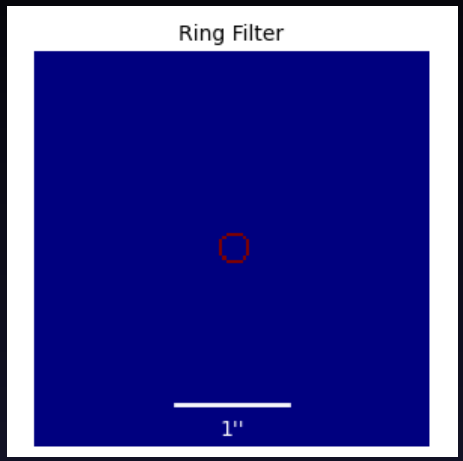

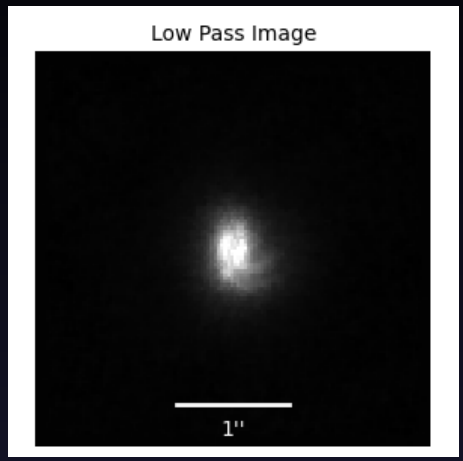

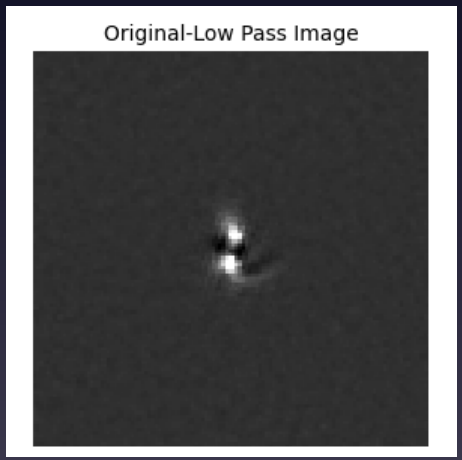

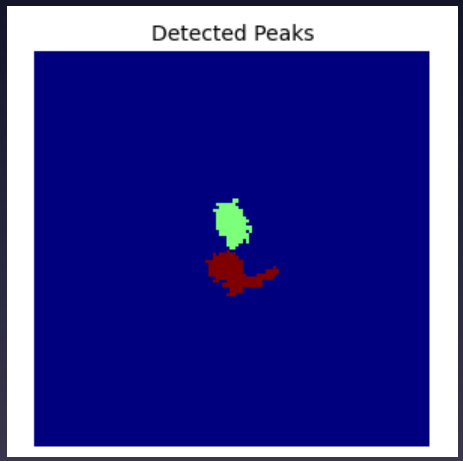

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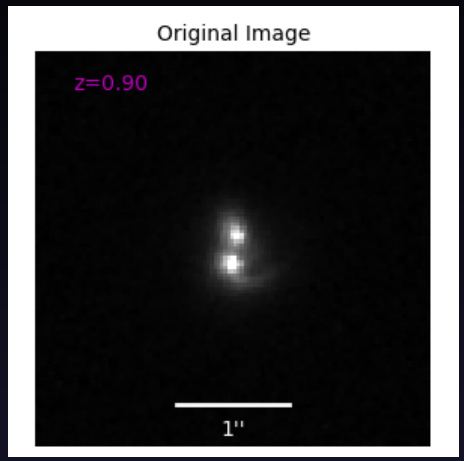

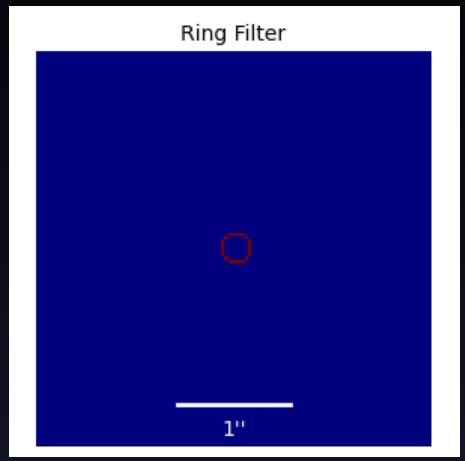

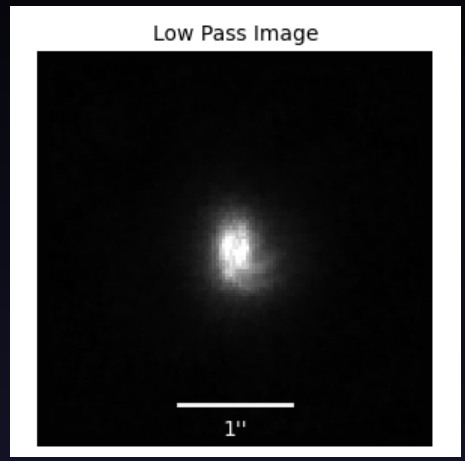

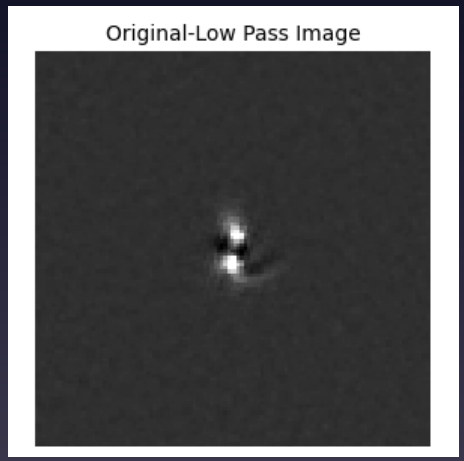

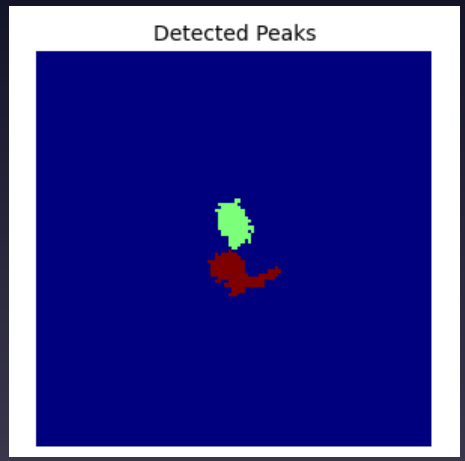

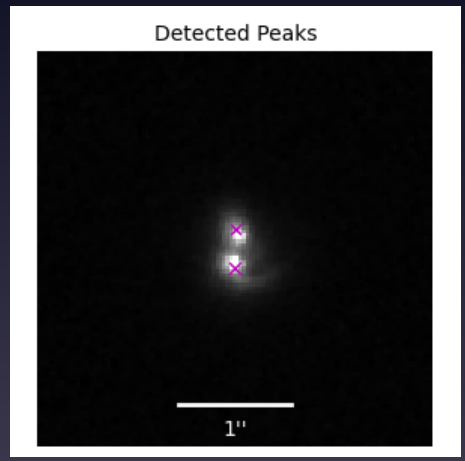

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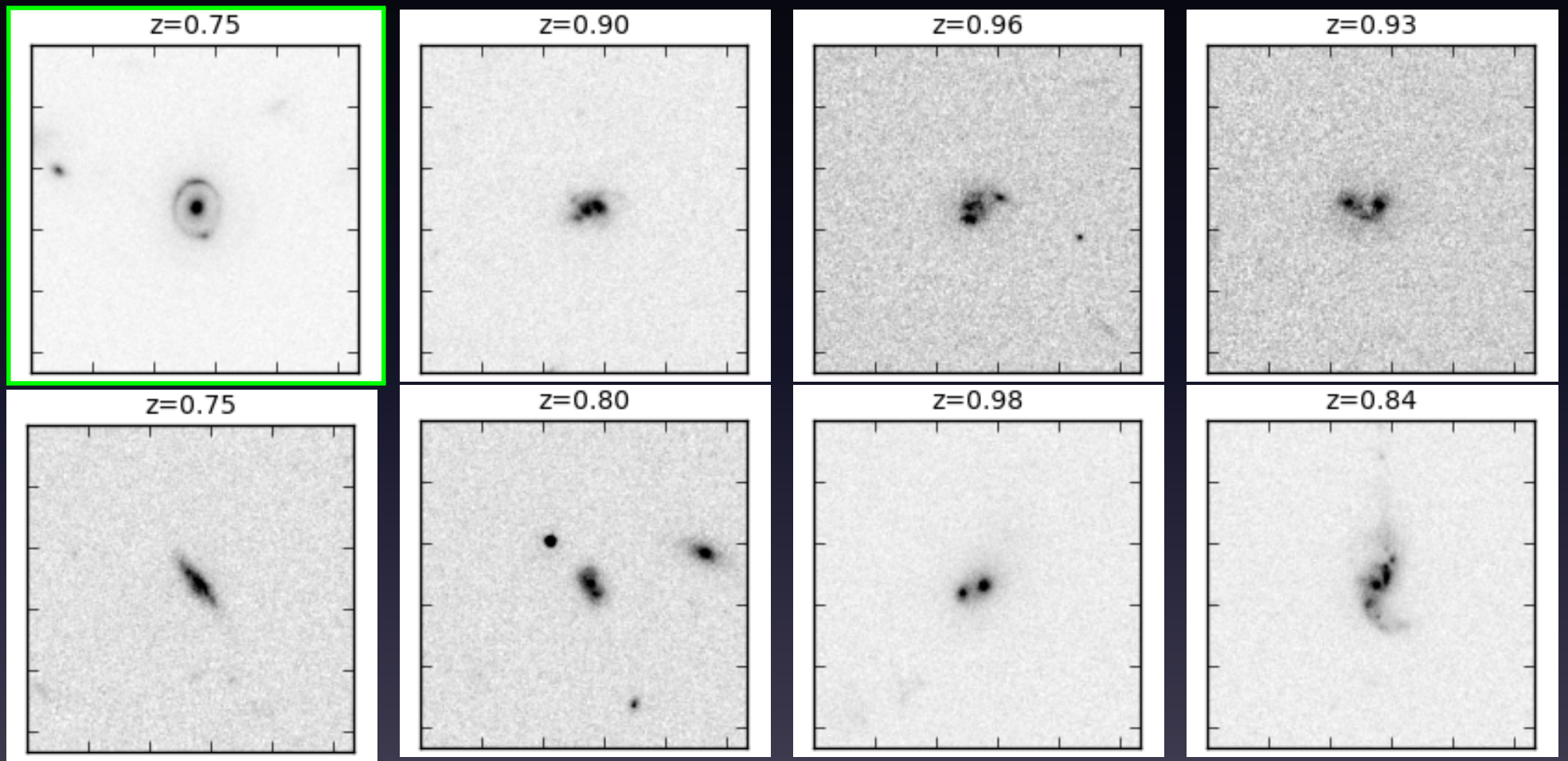
Sample from COSMOS

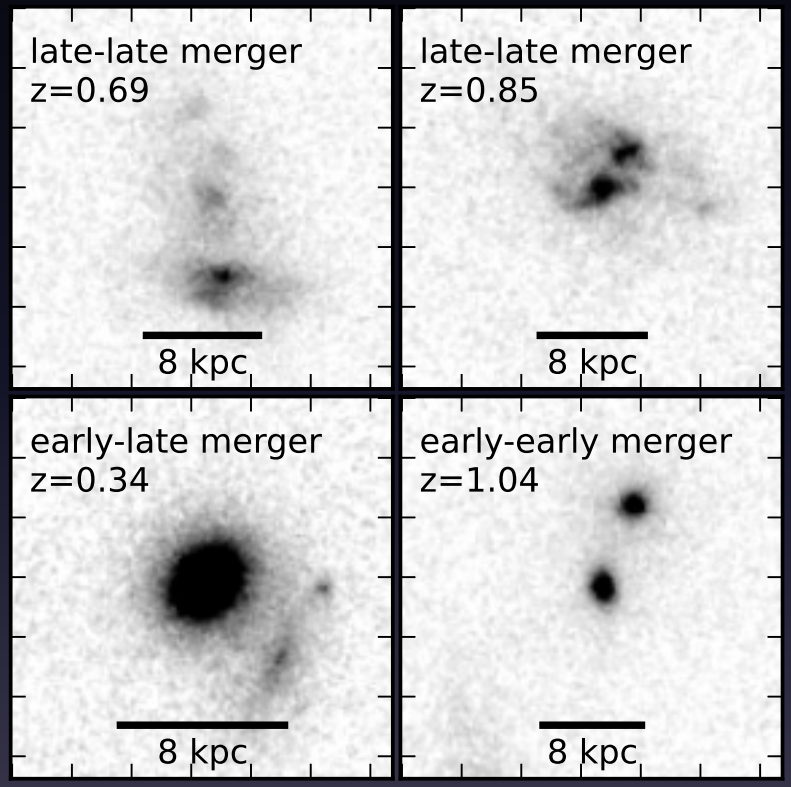
- Parent sample: 44,000 galaxies
- Redshift range: $0.2 < z < 1.0$ (photo-z from Ilbert, 2013)
- Magnitude limit: $m_{FW814} < 23$
- Method applied to HST/ACS images (0.03″/pixel)
- Physical separation limited between 2.2 and 8 kpc
- 1547 late-stage merger *candidates*
- $\sim$ 5% of massive galaxies ($\log M_*/M_\odot > 10.6$) are late-stage mergers

Late-Stage Mergers from COSMOS



Testing with Mock Merger Images

- Postage stamps for two galaxies co-added to make mock merger images
- Pair members have similar photo-zs
- Co-added at fixed separations
- Cannot account for structure changes due to merger



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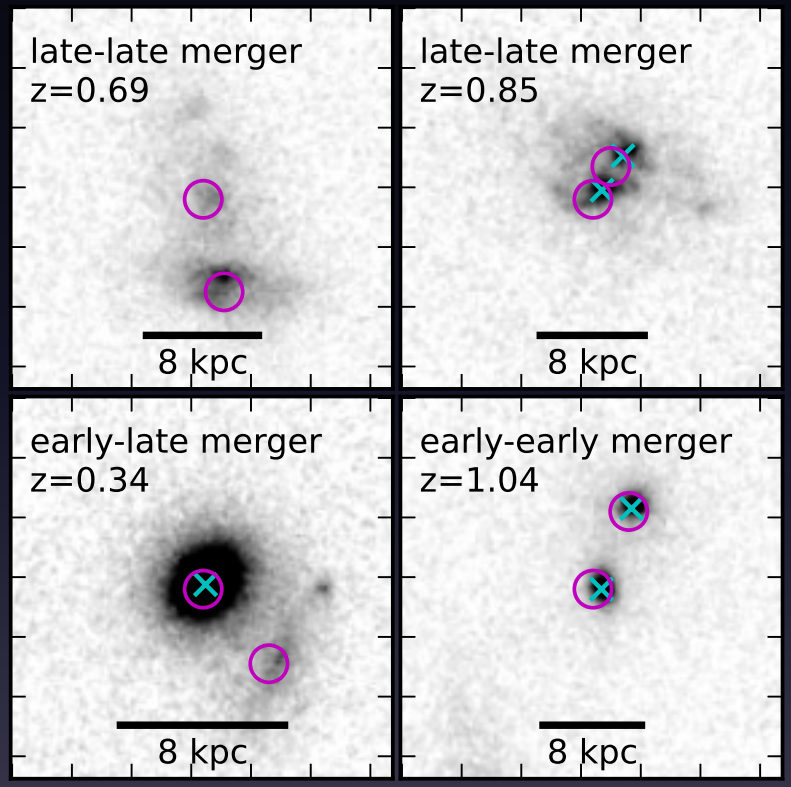
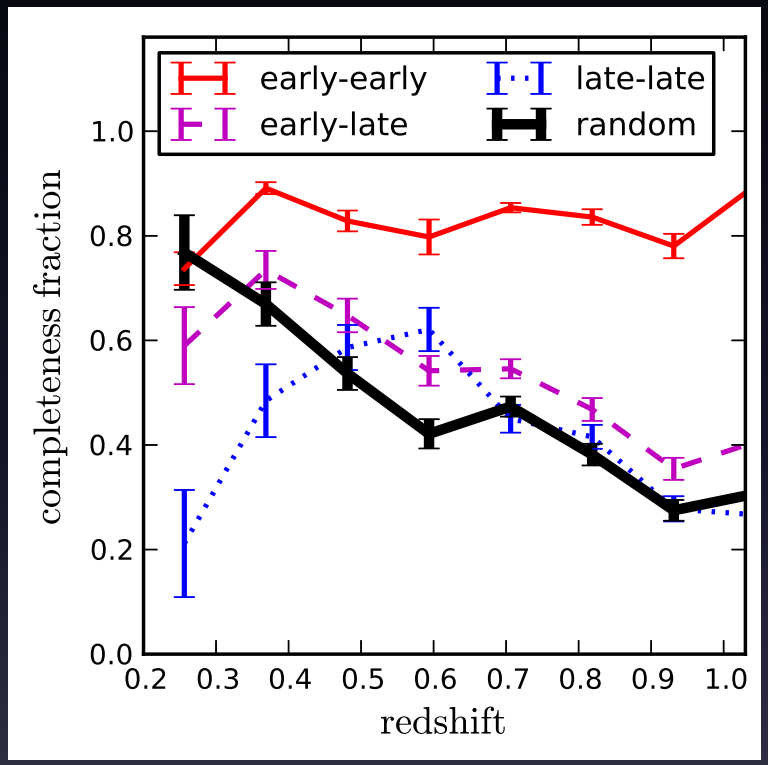
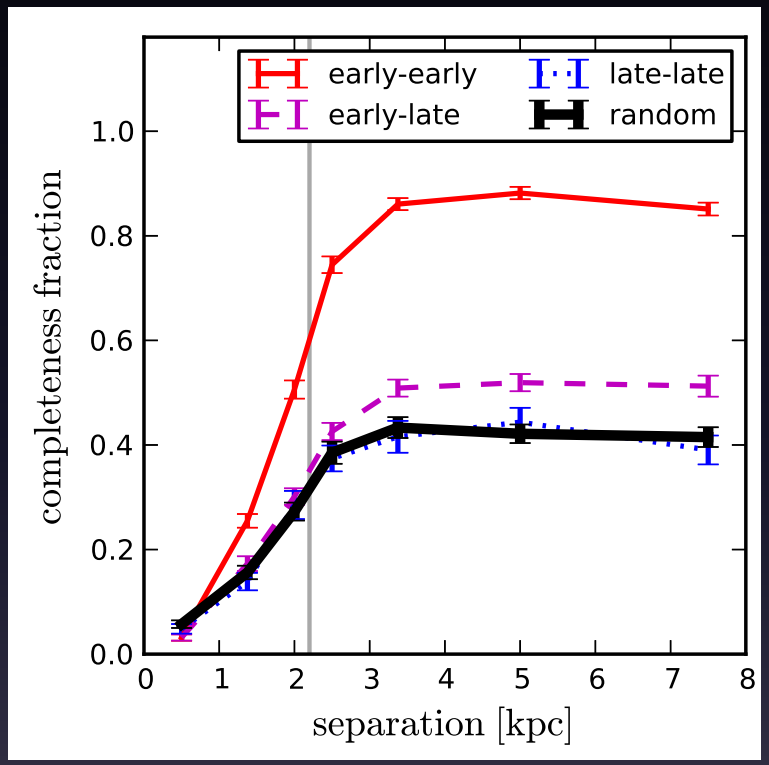


Completeness

as a function of redshift

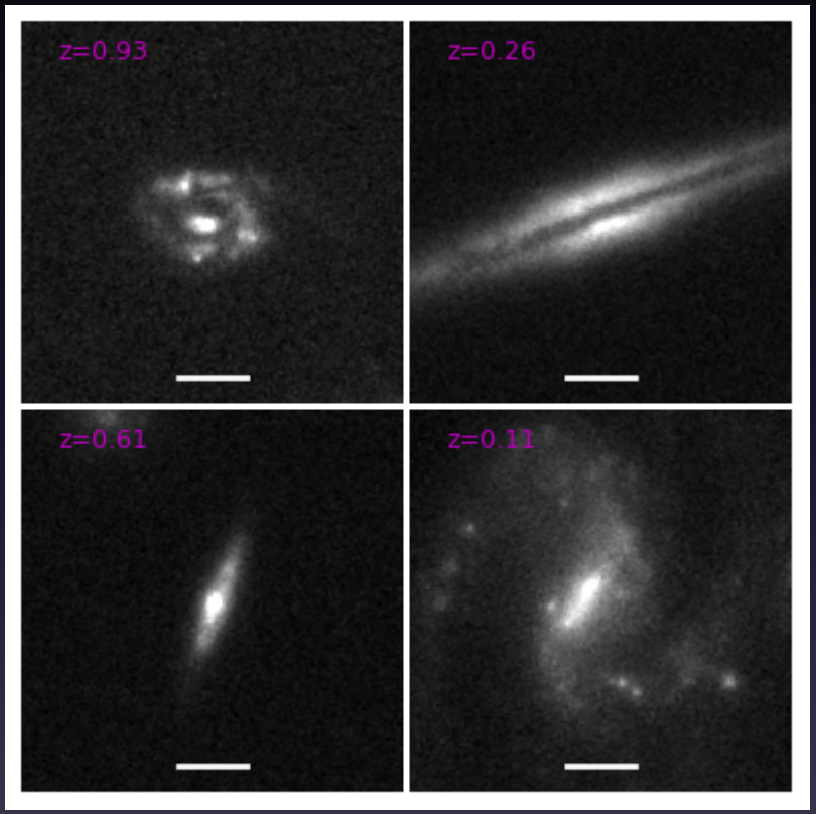


as a function of separation



Finding a merger depends strongly on the morphology of the constituent galaxies.

Contamination



- Contamination from chance superpositions, star-forming regions, disks with dust lanes, minor mergers
- Use flux ratio limits and detection thresholds to eliminate contamination
- Contamination $\sim$ 30% from non-mergers and minor mergers

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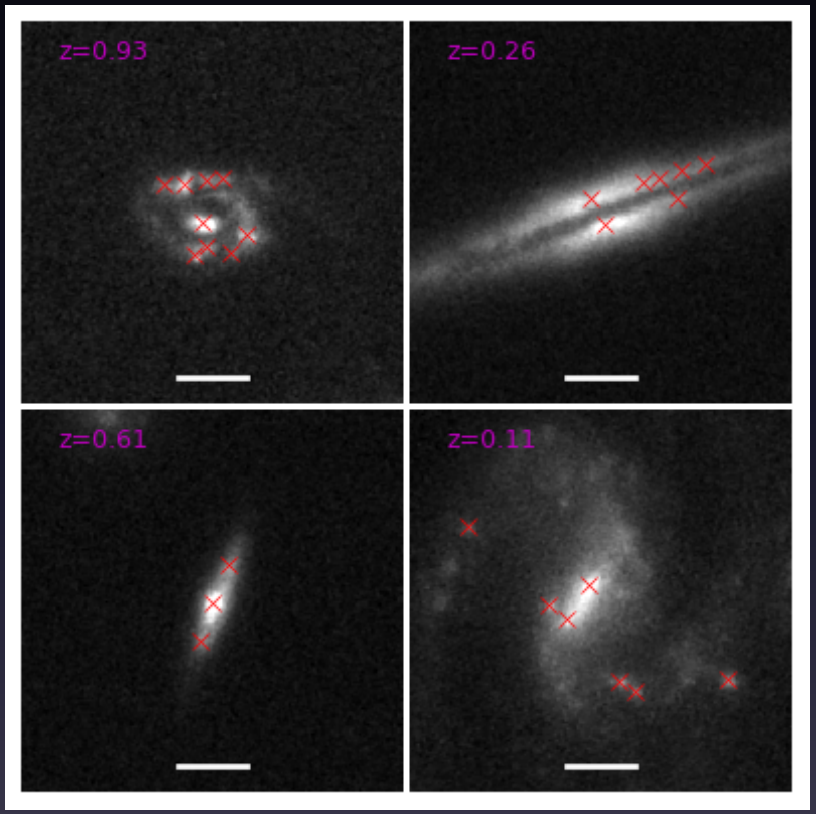

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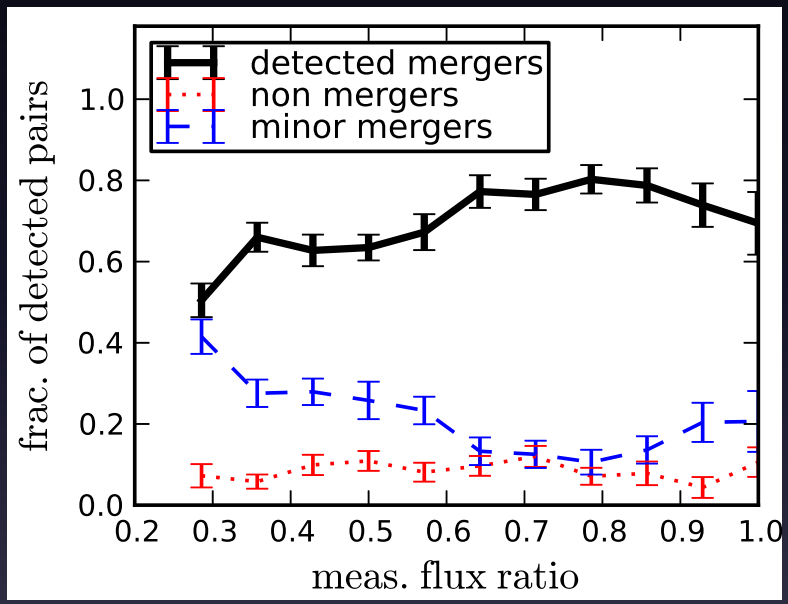

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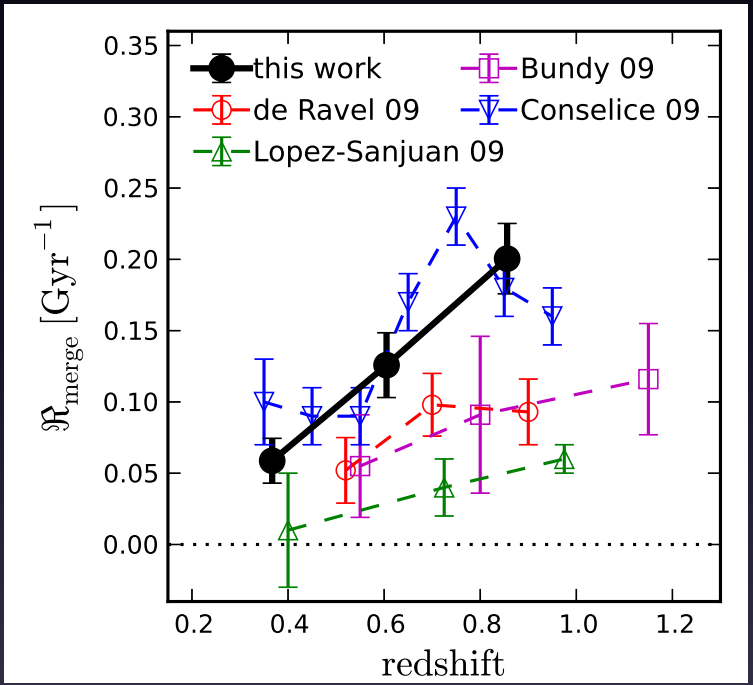
Merger Rates from Late-Stage Mergers

- Sample restricted to $\log M_*/M_\odot > 10.6$, mass complete
- The per galaxy merger rate

$$\Re_{\rm merge} = C_{\rm merge} f_{\rm pair} \langle \frac{1}{T_{\rm obs}} \rangle$$

- Correction factor $C_{\rm merge} \approx$ 0.7 chance super-positions $\times$ 0.67 non-mergers $\times$ $\sim 1-5$ incompleteness
- Timescale for observing mergers $1/\langle 1/T_{\rm obs} \rangle \approx 0.33$ Gyr (Lotz, 2011)



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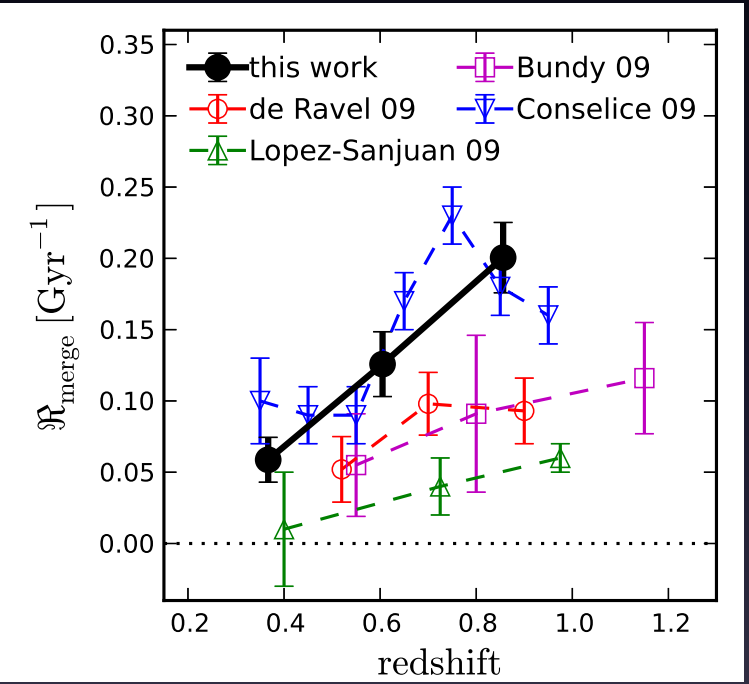

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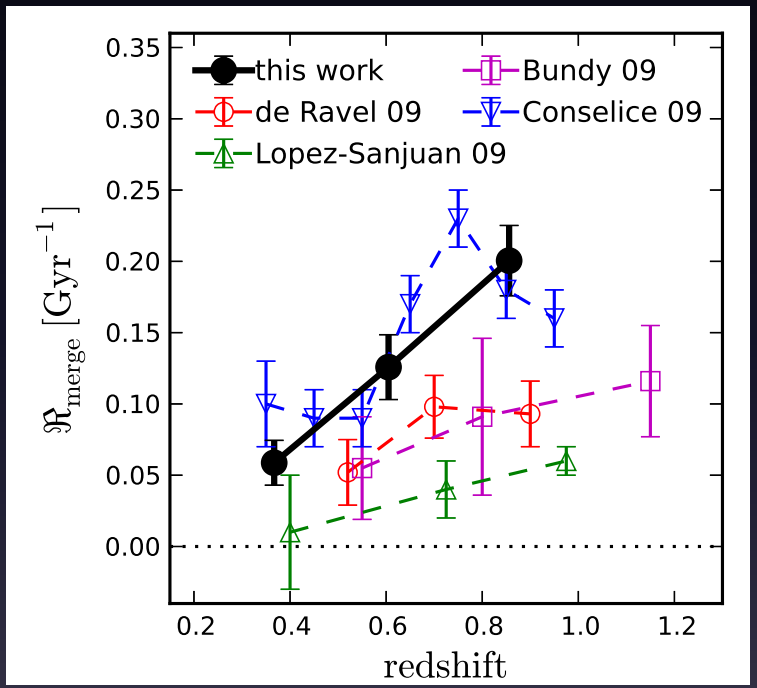
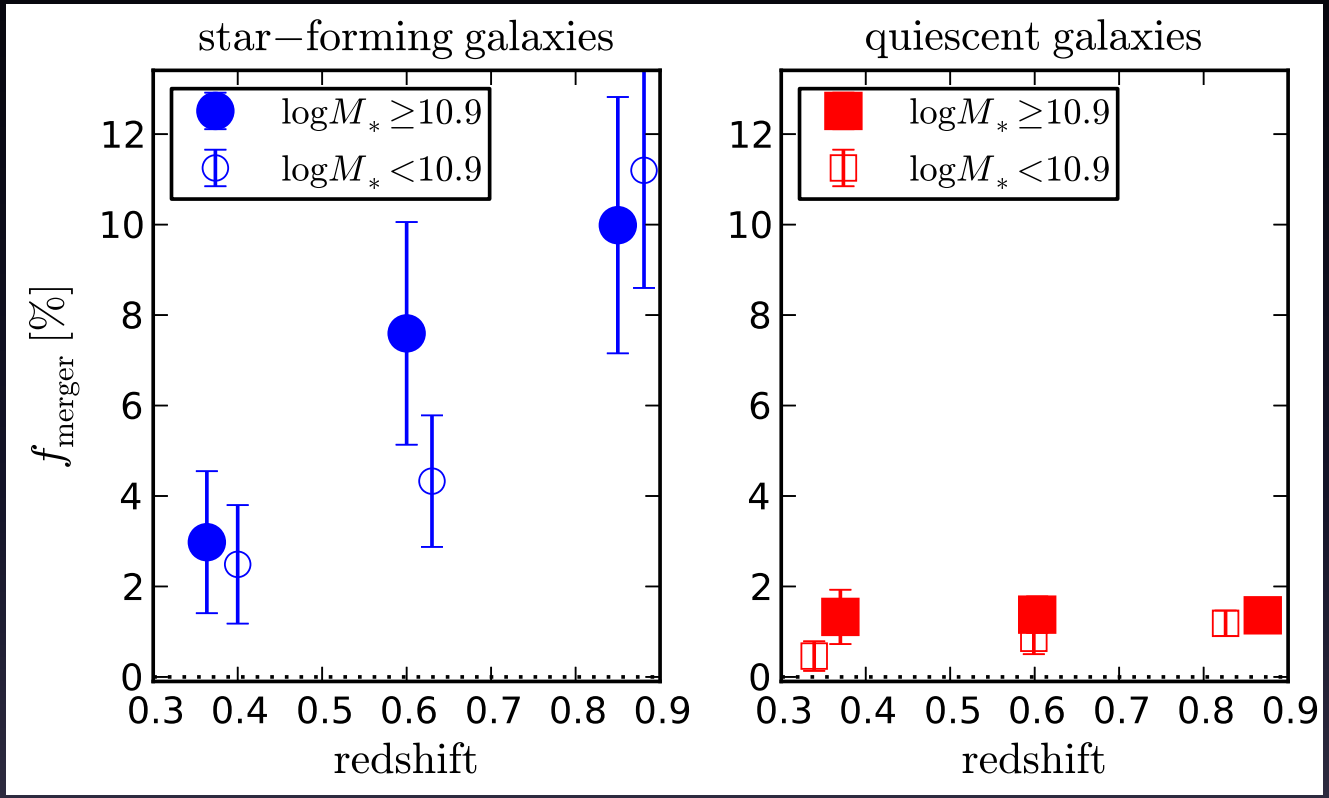


$\Re_{\rm merge} \propto (1+z)^{3.8\pm0.9}$

Merger Rate for Red and Blue Galaxies (I)

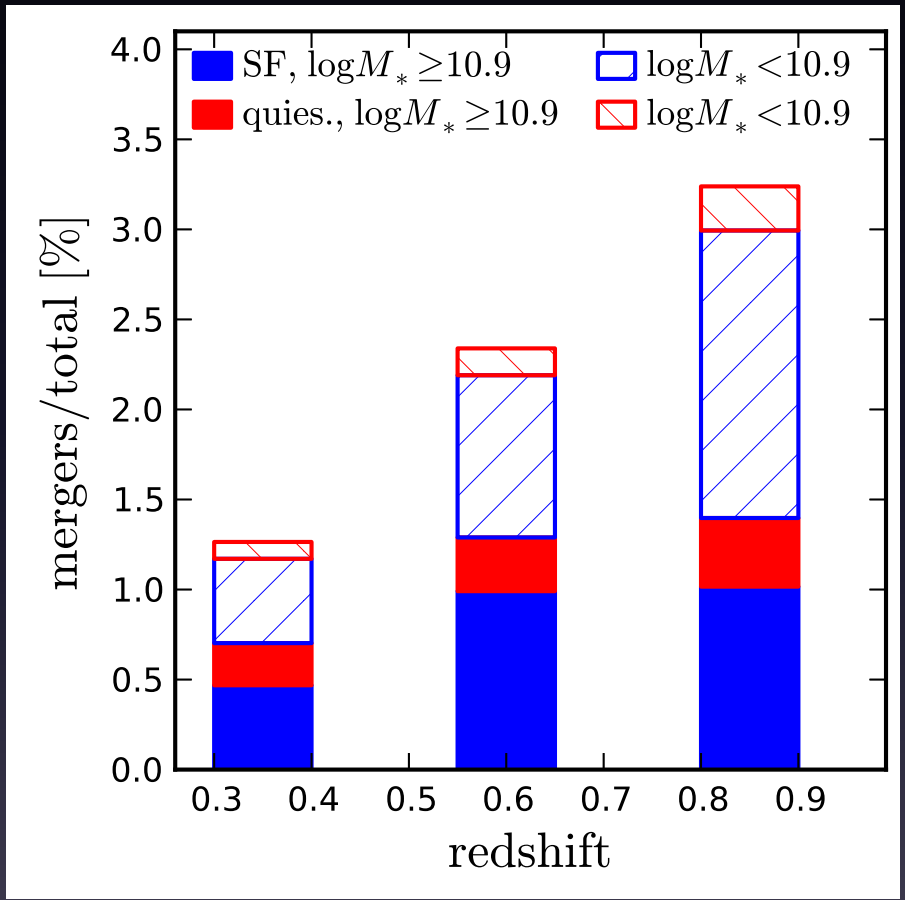


$\Re_{\rm merge} \propto (1+z)^{4.5\pm1.3}$ $\Re_{\rm merge} \propto (1+z)^{1.1\pm1.2}$

Uses different corrections factors ($C_{\rm merge}$) for red and blue galaxies.

Merger Rate for Red and Blue Galaxies (II)

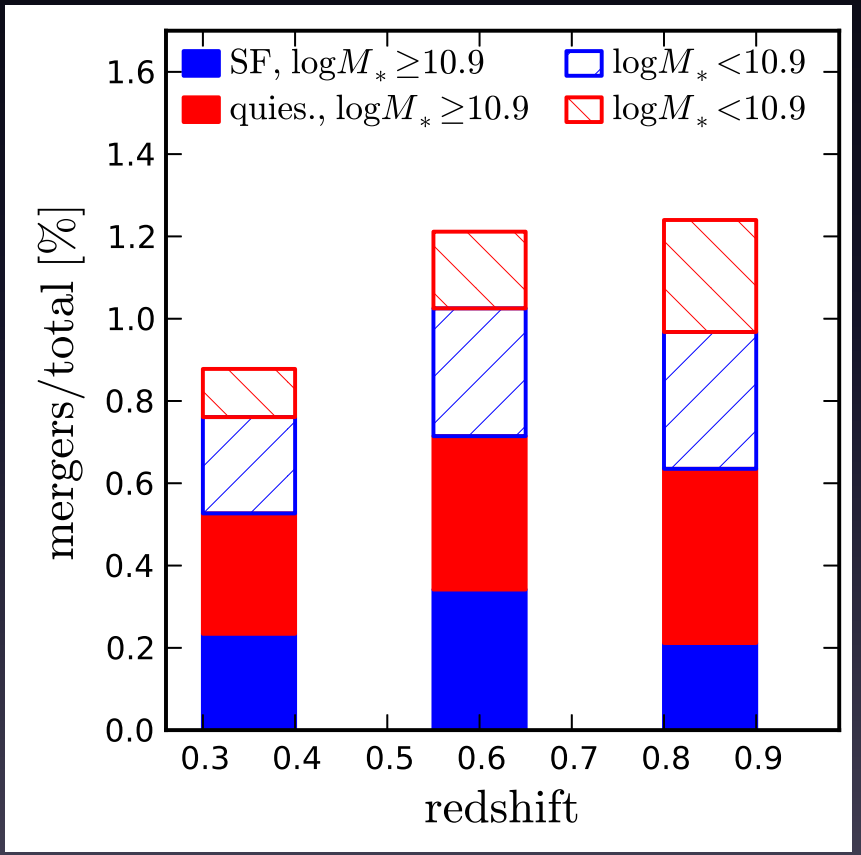
- Growth in merger rate driven by SF galaxies
- Increase in fraction of SF mergers driven by increase in SF galaxy fraction
- Different samples/populations have different merging histories



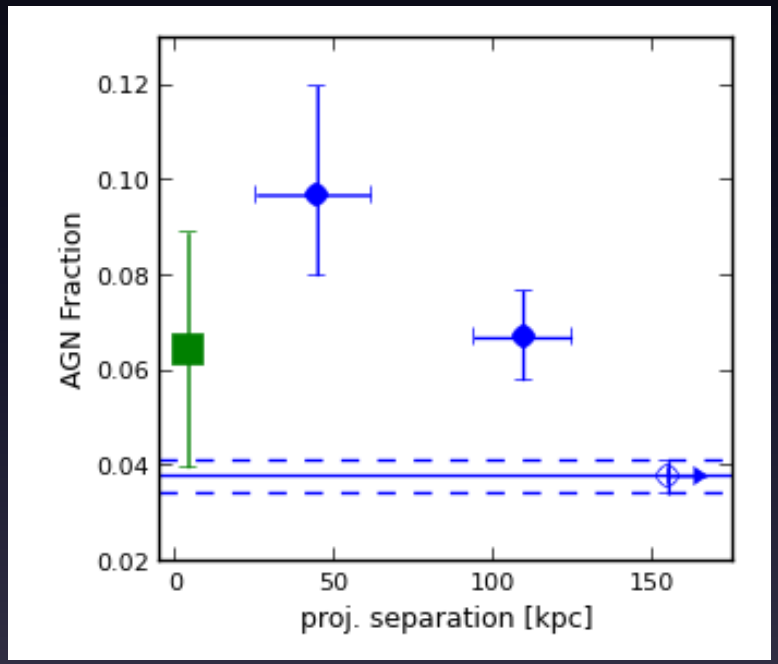
Merger Rate for Red and Blue Galaxies (II)

without redshift dependent completeness correction

- Completeness correction mainly affects SF galaxies
- Redshift evolution largely from completeness correction
- $\Re_{\rm merge} \propto (1+z)^{0.8\pm0.8}$



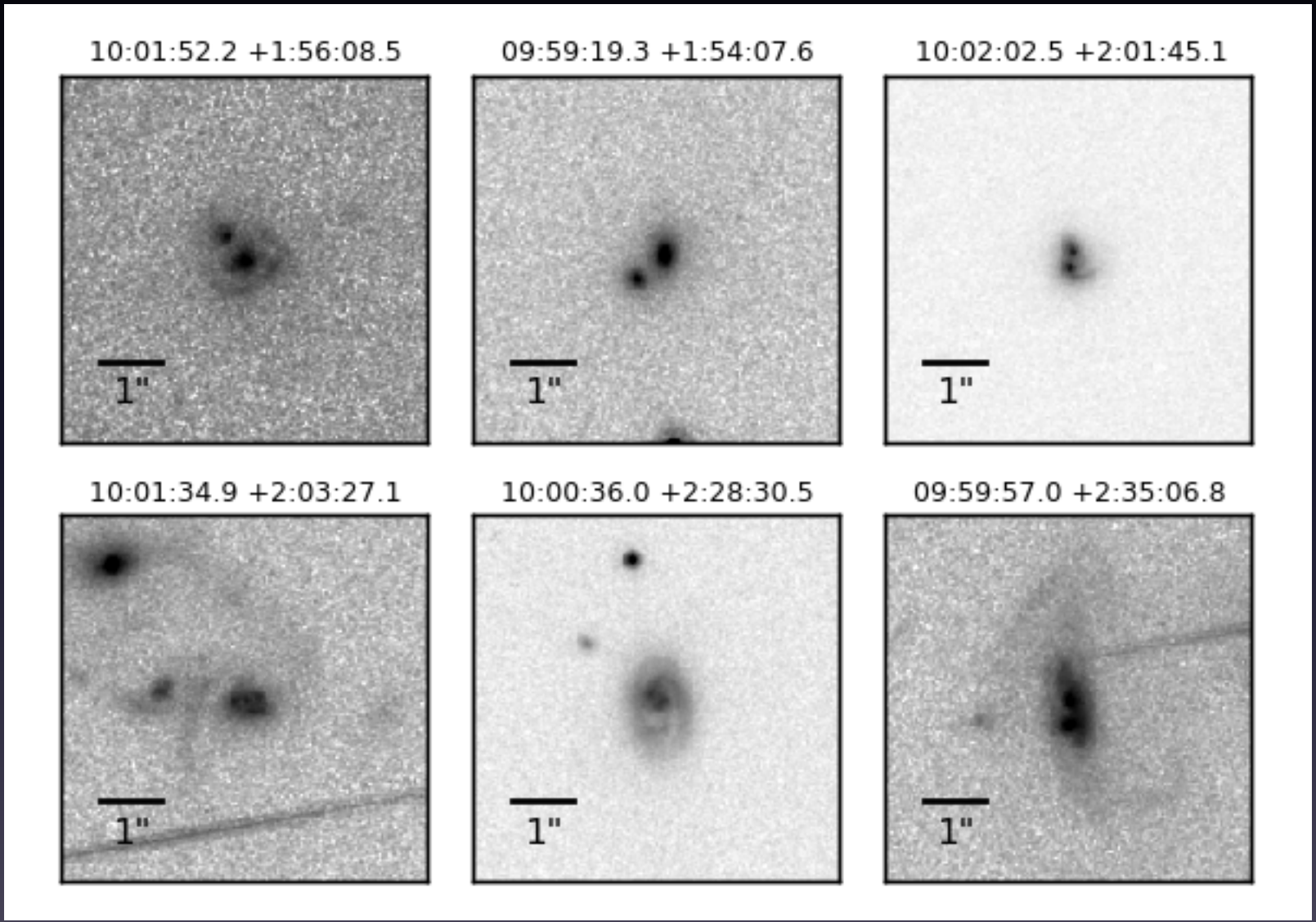
AGN Fraction Compared to Field Galaxies



Pair data from Silverman, 2011

- zCOSMOS + Chandra footprint
- 3481 galaxies with $M_* > 2 \times 10^{10} M_\odot$ and $0.25 < z < 1.05$
- 112 late stage mergers (6 x-ray sources)
- Upper limit on AGN enhancement is 3 (median, 1.7 ± 0.7)
- $20.0 \pm 0.8\%$ of AGN activity due to mergers (incl. wide pairs)

Late-Stage Mergers with an AGN



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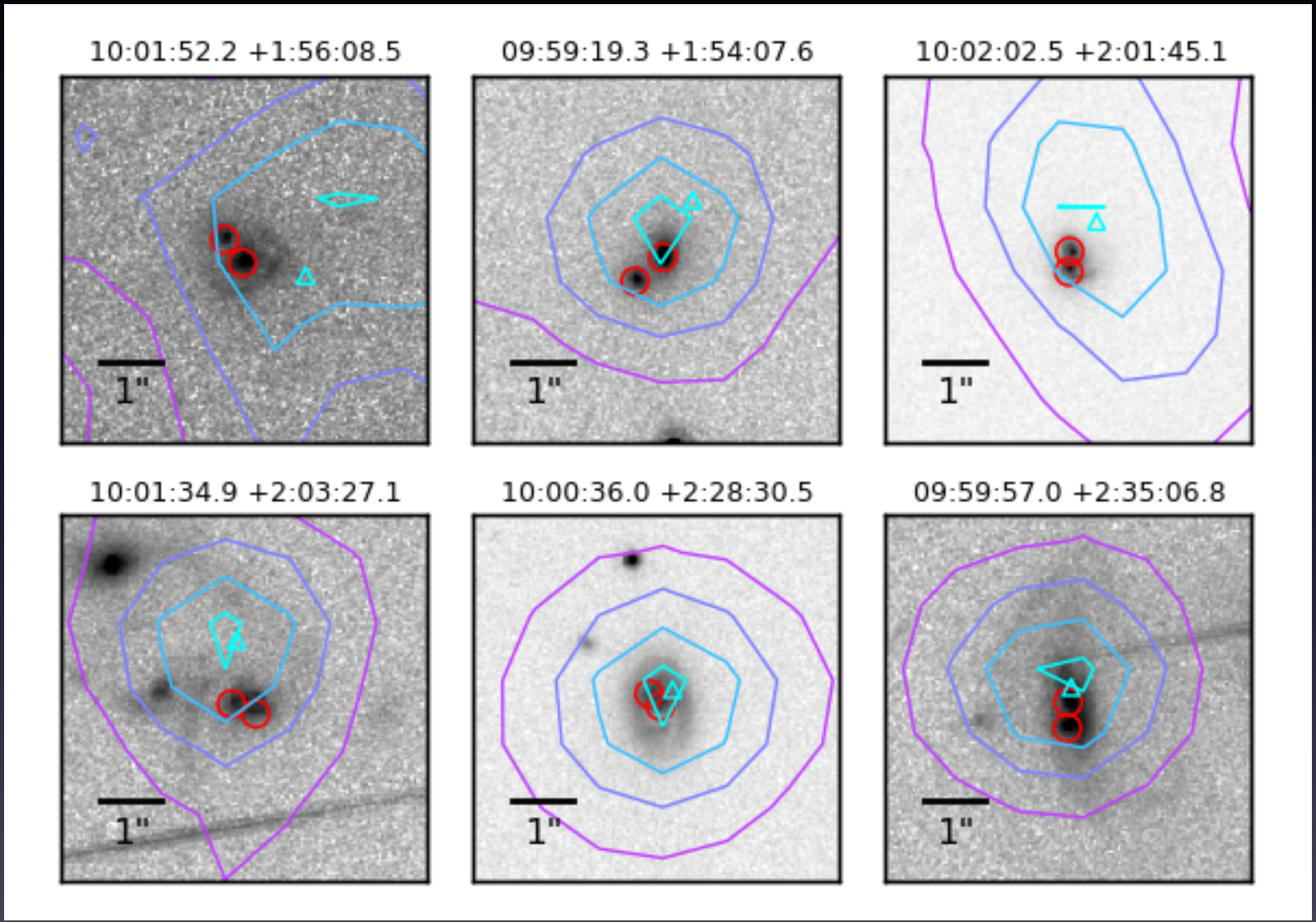
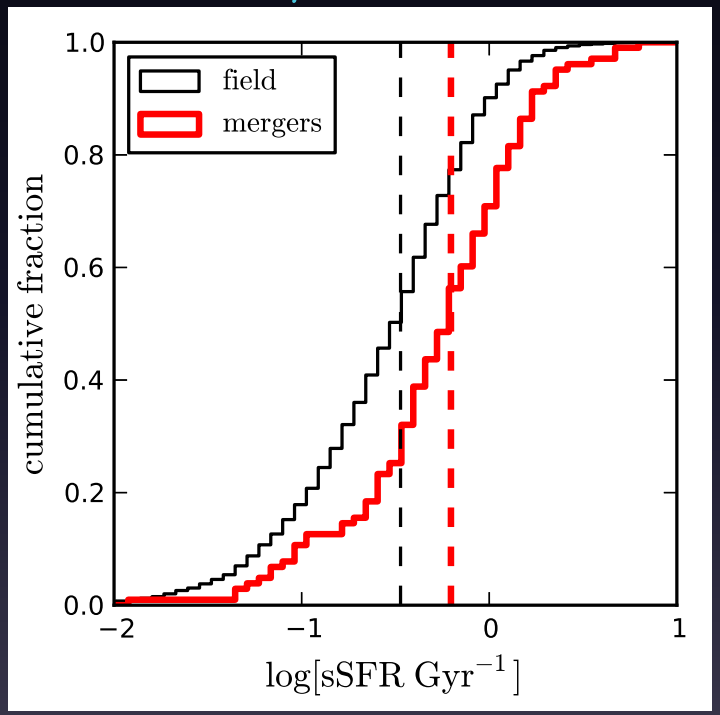
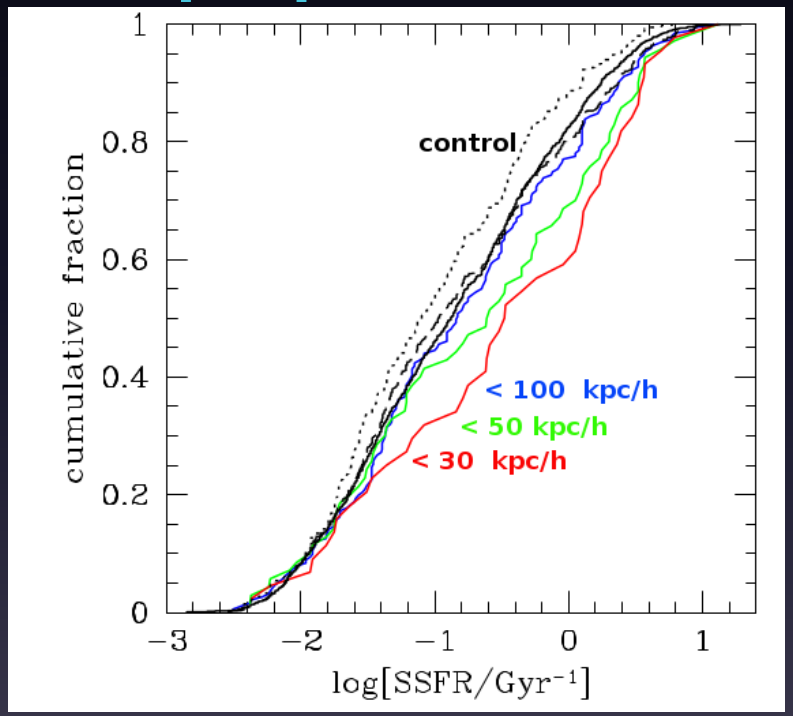


SFR in Late-Stage Mergers

late-stage mergers
24 μm SFR



kinematic pairs
[O II]λ3727 SFR



Kampczyk, 2013

- SFR enhanced by 2.1 $\pm$ 0.6 for late-stage mergers
- 18 $\pm$ 5% of SF occurs in mergers; 8 $\pm$ 5% due to mergers

Summary

- Median filtering effectively selects galaxy near coalescence
  - automated method
  - requires correction for incompleteness
- Evolution of the merger rate
  - $\Re_{\rm merge} \propto (1+z)^{3.8\pm0.9}$
  - quiescent galaxies show no evolution in merger rate
  - mergers between star-forming galaxies increase with z
- AGN fraction and star formation rates enhanced by $\sim 1-3\times$.
  - at most 20% of AGN are **triggered** by close interactions
  - $\lesssim$ 10% of SF **triggered** by merging

To $z \sim 1$, mergers are not the dominant driver of AGN or SF

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Solutions to Contaminants

Can remove most contaminants by checking detected multiple peaks:

- Peaks must be within **2.2-8 kpc** ($\sim 1''$)
  Eliminates resolved pairs of sources
- Δmag$<$ 1.9 for peaks in same source
  Corresponds to $\sim$ **1:3 merger ratio**
  Eliminates small star-forming regions
- Peaks contain more than $\sim$ 2% of total galaxy flux
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- Three or more peaks cannot form a line ($\rho_{\mathrm{pearson}} < 0.5$)
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- Thresholds and ring size can be adjusted for different data

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  Eliminates edge-on disks
- Thresholds and ring size can be adjusted for different data

return

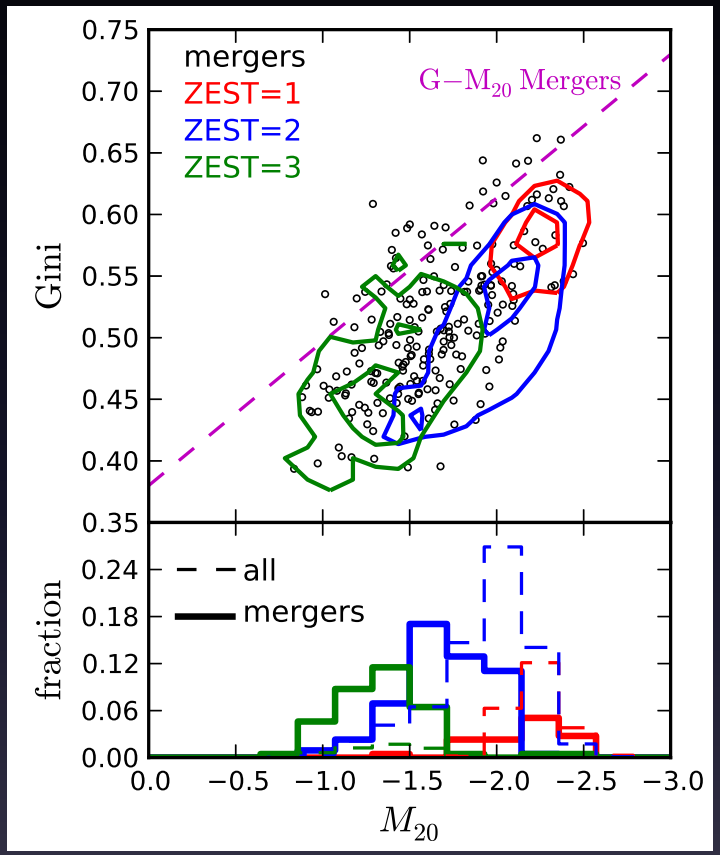
Solutions to Contaminants

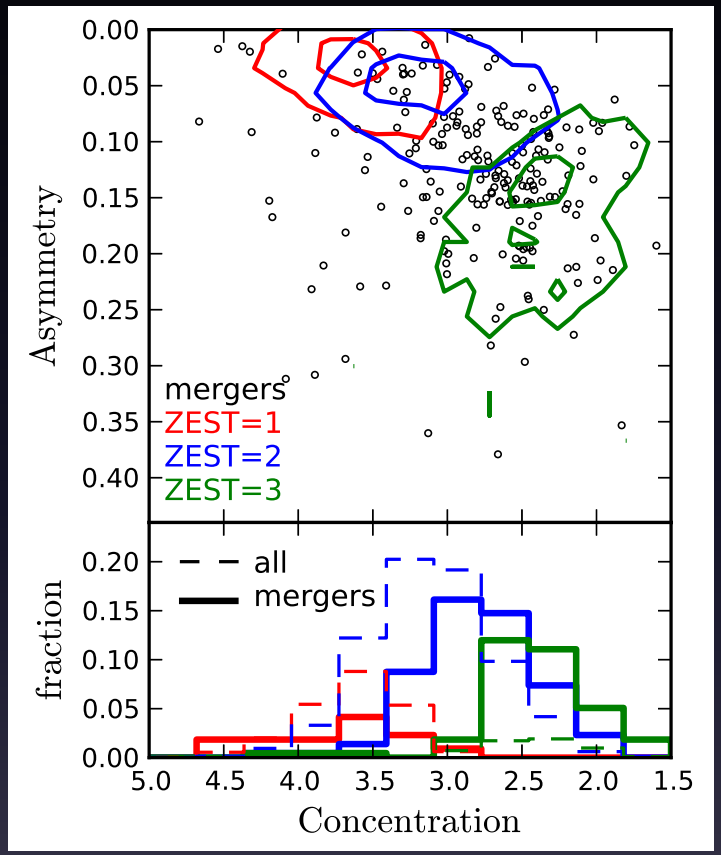
Can remove most contaminants by checking detected multiple peaks:

- Peaks must be within **2.2-8 kpc** ($\sim 1''$)
  Eliminates resolved pairs of sources
- Δmag$<$ 1.9 for peaks in same source
  Corresponds to $\sim$ **1:3 merger ratio**
  Eliminates small star-forming regions
- Peaks contain more than $\sim$ 2% of total galaxy flux
  Eliminates small star-forming regions
- Three or more peaks cannot form a line ($\rho_{\mathrm{pearson}} < 0.5$)
  Eliminates edge-on disks
- Thresholds and ring size can be adjusted for different data

◂ return

G-M_{20} and Asymmetry Selections





Pairs have *slightly* higher Gini coefficient, but majority are below merger criterion (Lotz, 2008).

Pairs have lower concentration values, but not very high asymmetry.

70μm Galaxies

- 70μm-selected galaxies from Kartaltepe, 2009
- Extremely close pairs are 5% of 70μm-selected galaxies
- $<$ 2% of full sample
- Agrees with SFR enhancement of $\sim 2-3$