Clumpy Star-forming Galaxies from z~3 to z~0.5

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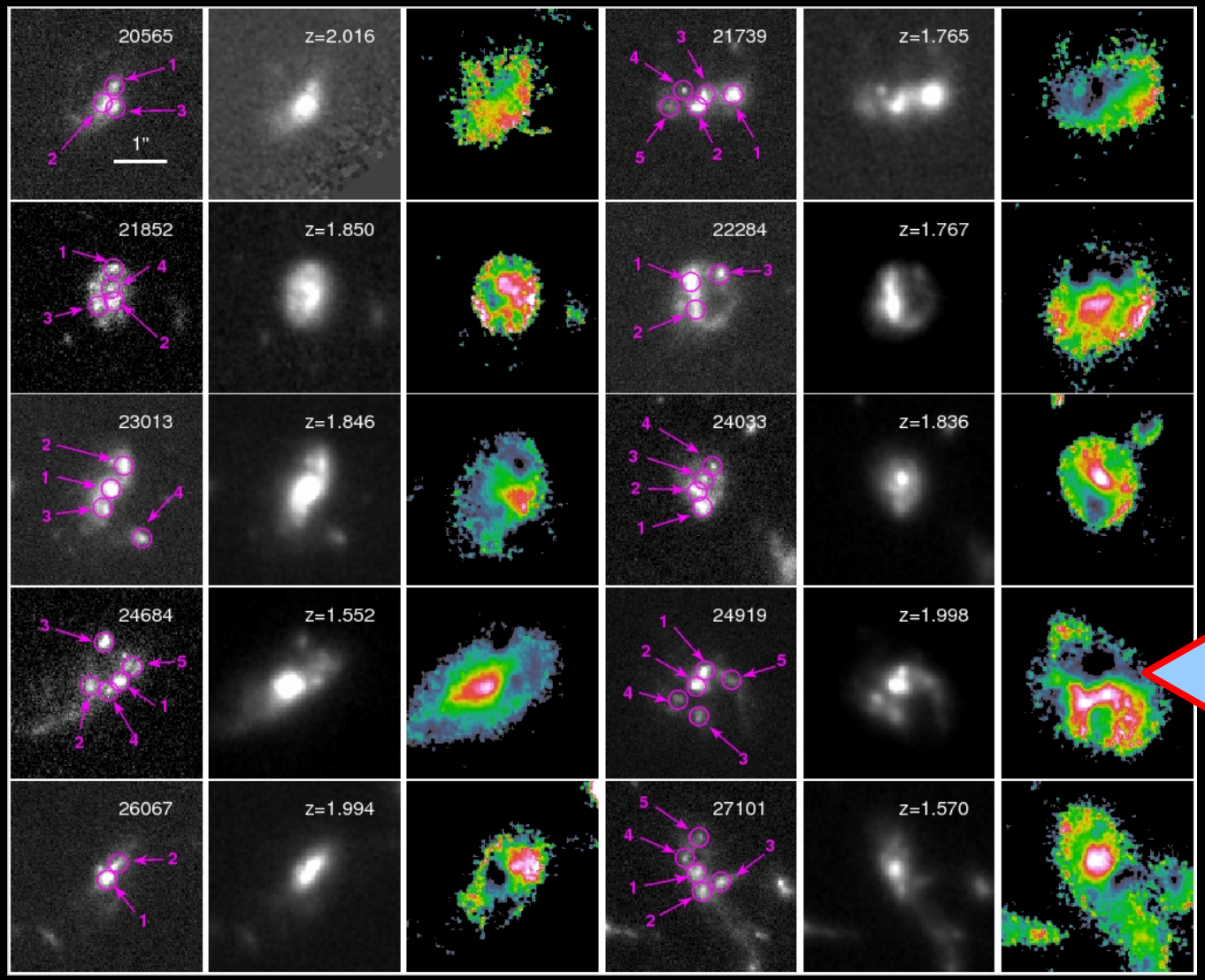

Collaborators:
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Examples of clumpy galaxies at z~2 (Guo+12)

Clumps: Ideal Laboratory of Star Formation, Feedback, and Galactic Structure Formation

- **Formation:**

  (1) Violent disk instability (VDI) in gas-rich turbulent disks?

  (2) Minor merger?

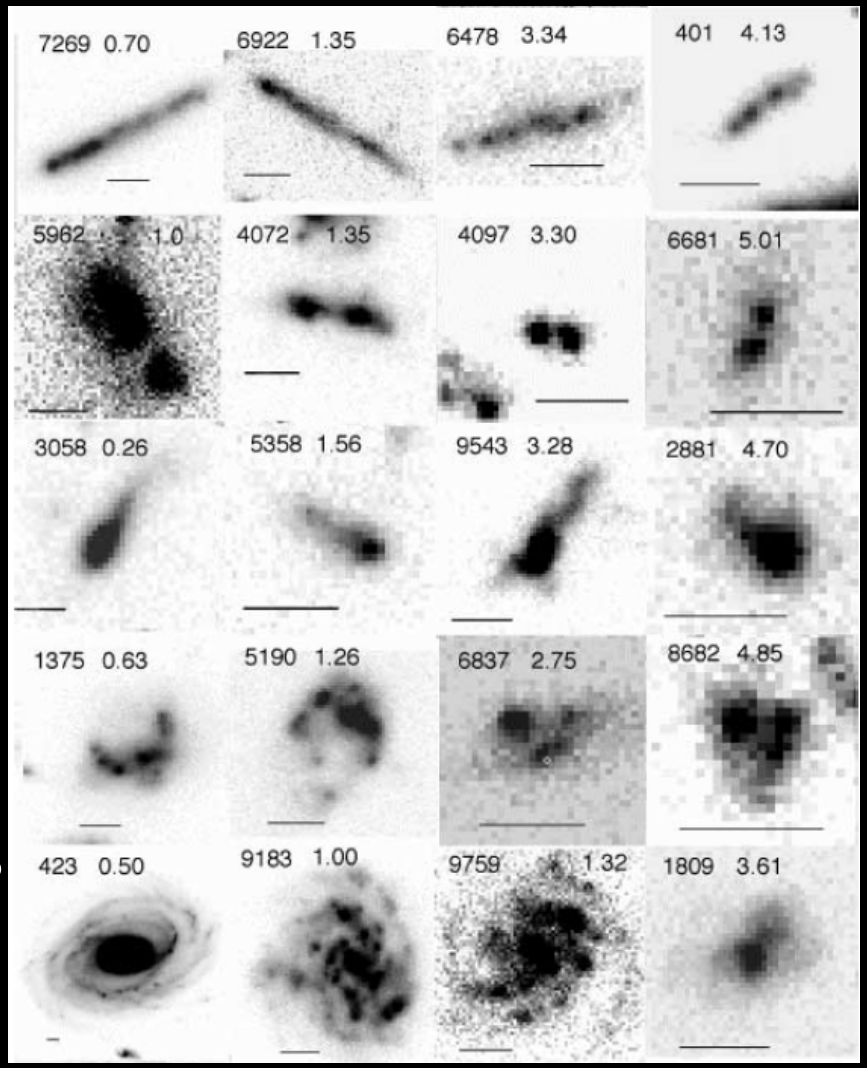
  (3) Major merger?

- **Evolution:**

  (1) Forming bulge progenitors?

  (2) Disrupted by feedback?

  (3) Connection with AGN/SMBH?



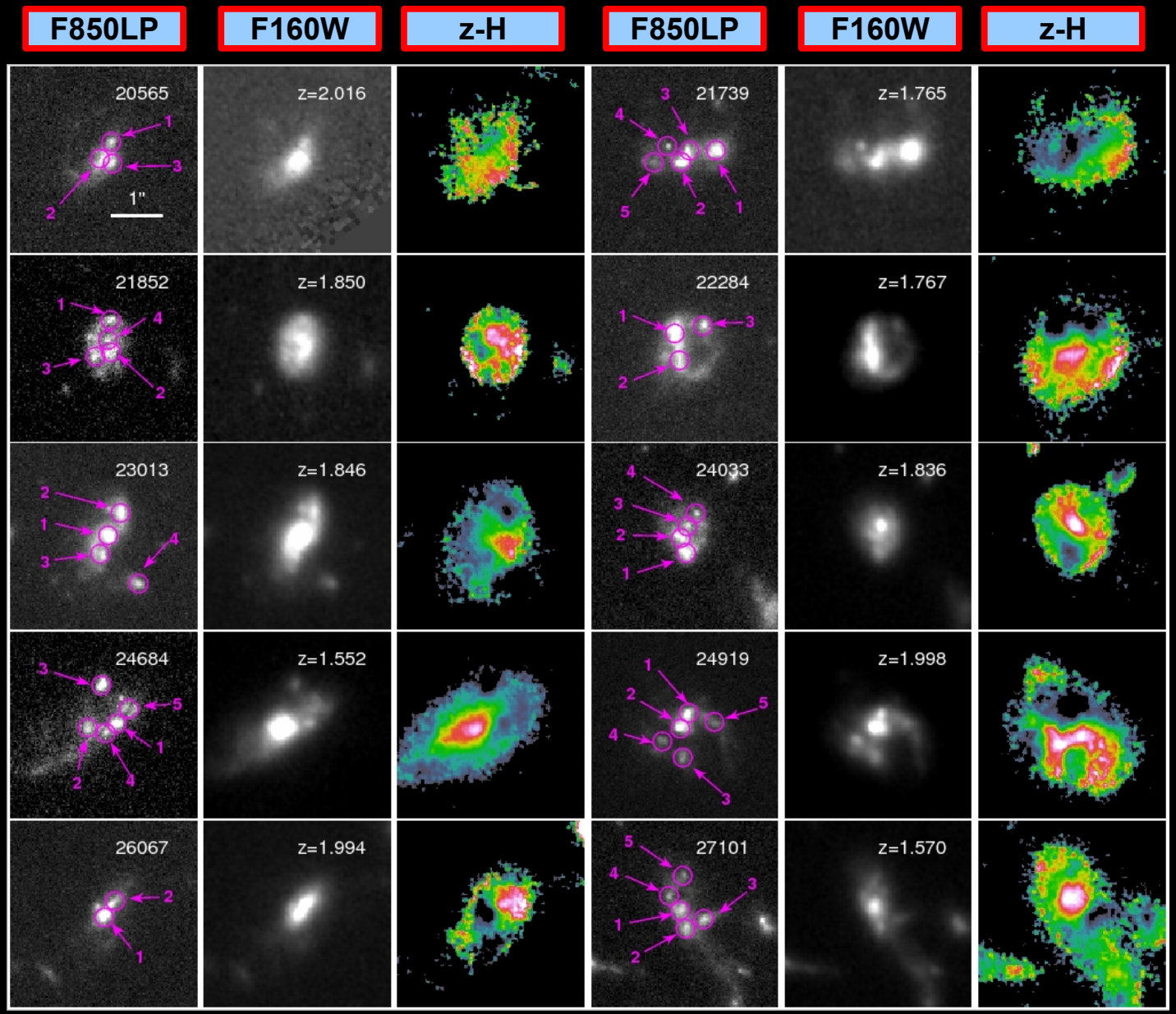
Elmegreen et al. (2007)

This talk: tracing clumpy galaxies from z=3 to z=0.5

- Physical properties of clumps and their variations at z~2 (Guo+12)
- Clumpy fraction of star-forming galaxies from z=3 to z=0.5 (Guo+14, submitted)
- Connection between clumps and galaxy kinematics at z~0.5 (preliminary)

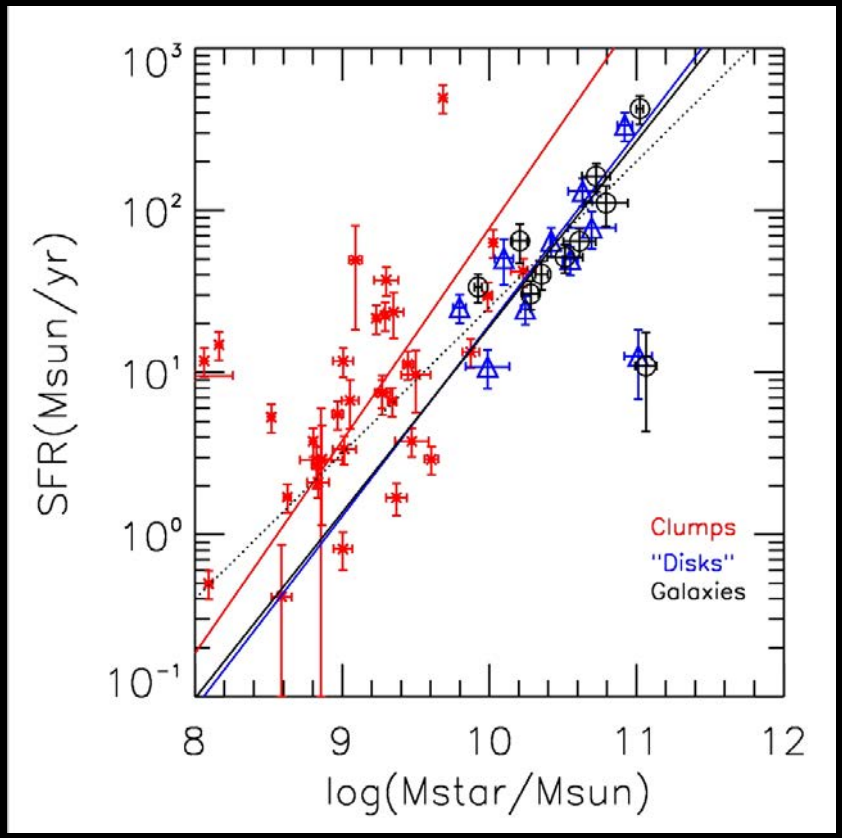
Part I: Physical Properties of Clumps at z~2

- 10 galaxies from HUDF
- Spec-z (1.5~2.5)
- log(M*)>10.0
- Star-forming

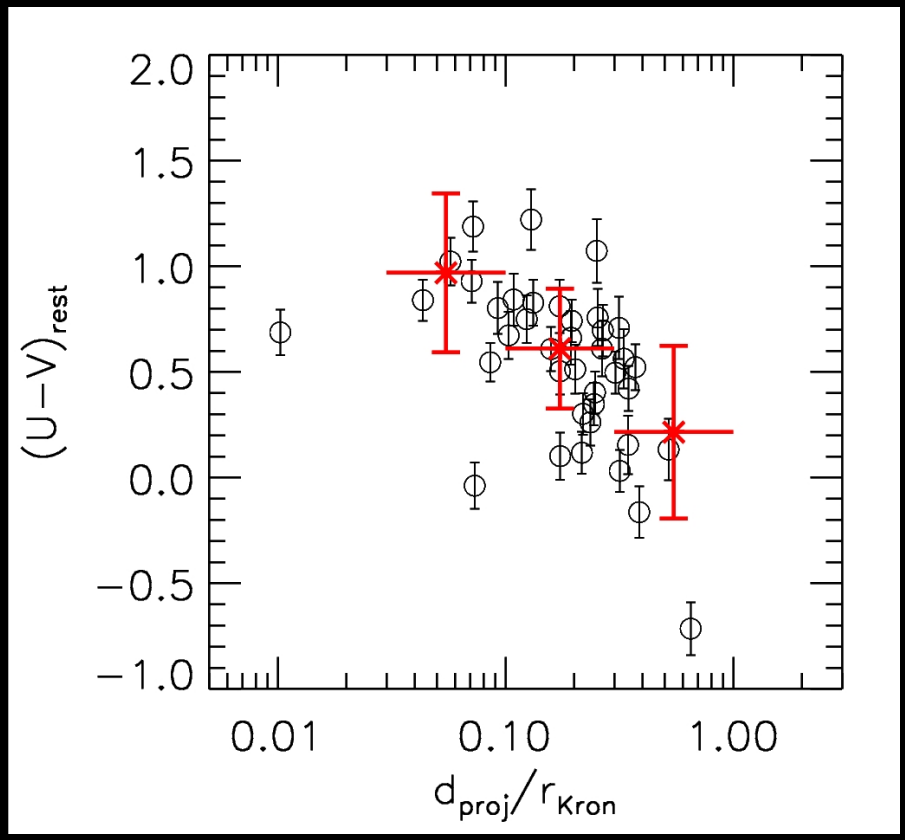


Physical Properties of Clumps

- Clumps are blue
- SFR of galaxies still dominated by disks
- Clumps have higher sSFR

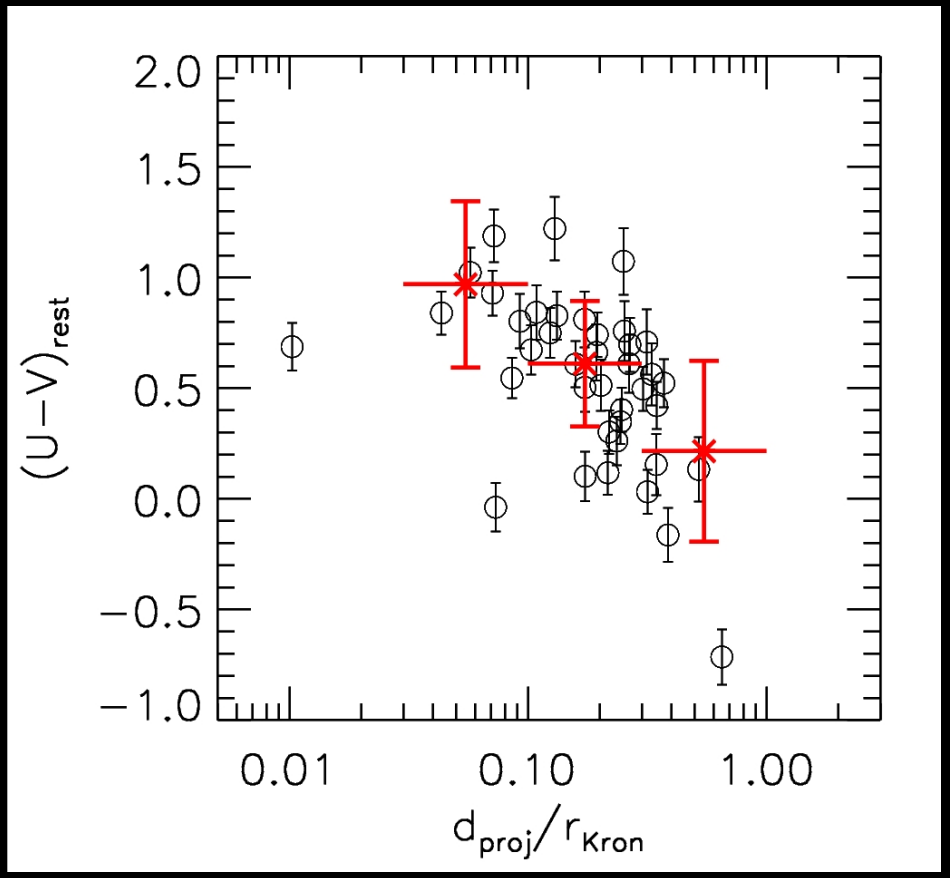


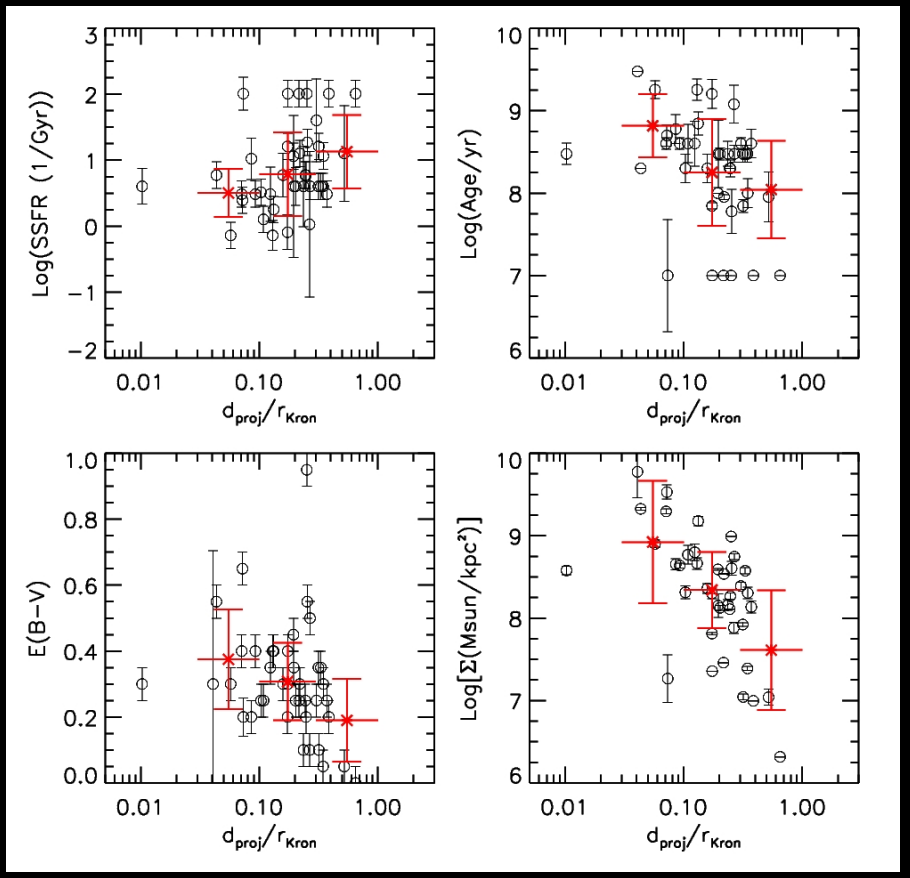
- Clumps have radial variation of the UV—optical colors
- Central clumps are redder, outskirt clumps bluer



Radial Variations Consistent with the In-ward Migration Scenario

- Clumps sink to the center of galaxies to form the progenitor of bulges
- During the migration, clumps become redder, older, denser, and less star-forming





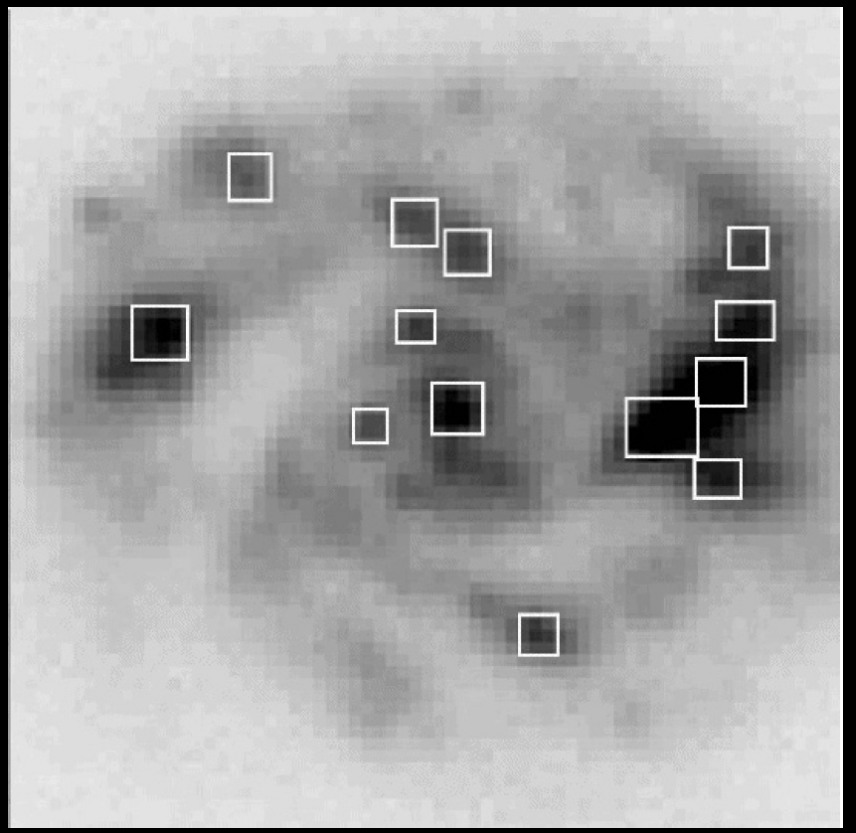
Part II: Clumpy Fraction from z=3 to z=0.5

I. How many star-forming galaxies are clumpy?

II. How much do clumps contribute to the SFR of their galaxies?

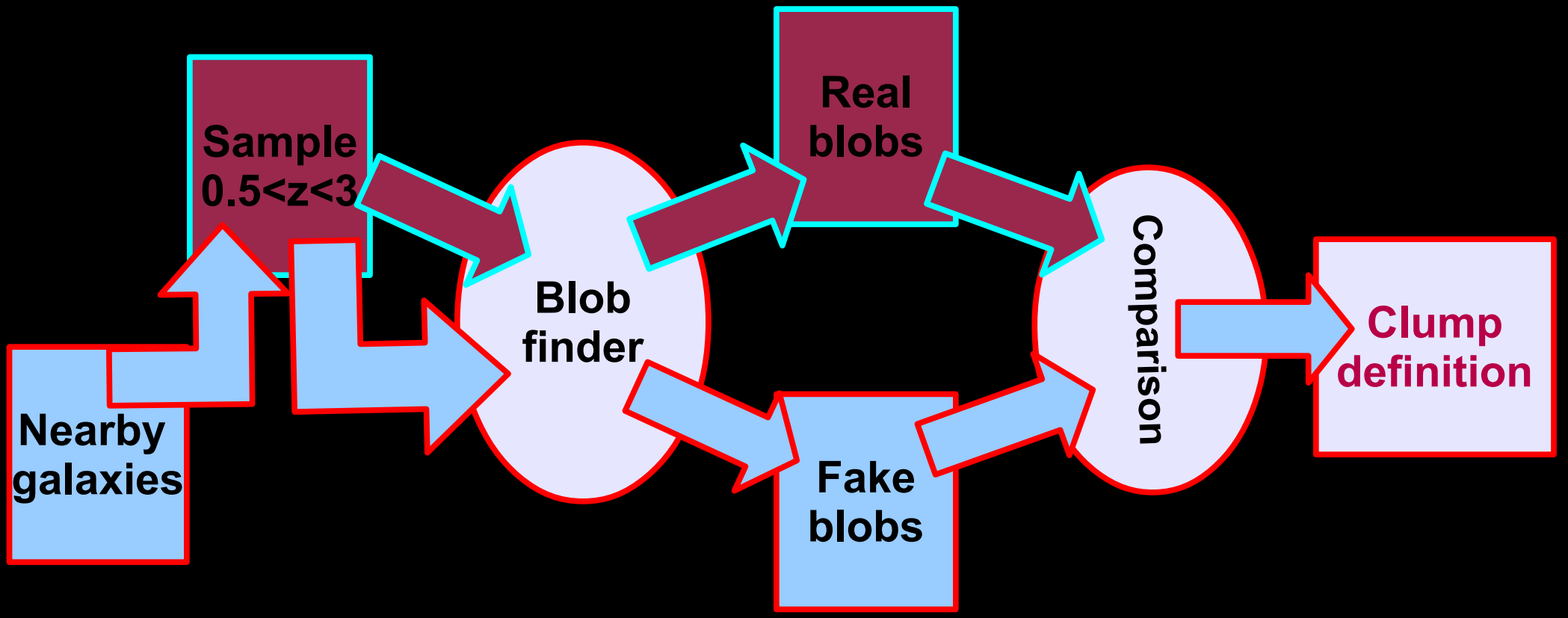
Key: need a physical definition of clumps

M101



z~1

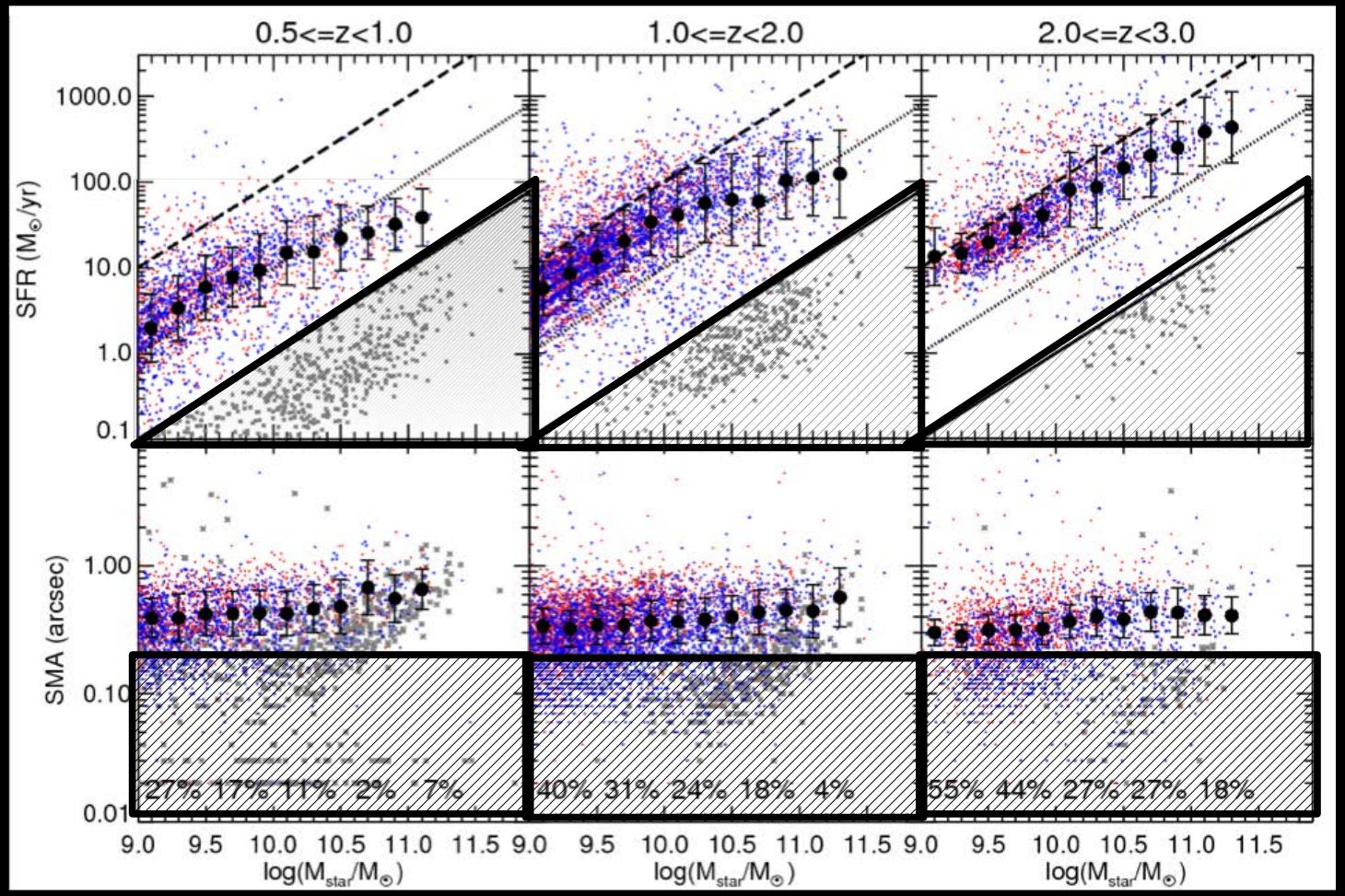
A Route Map to Clump Definition



"blob" = discrete star-forming region

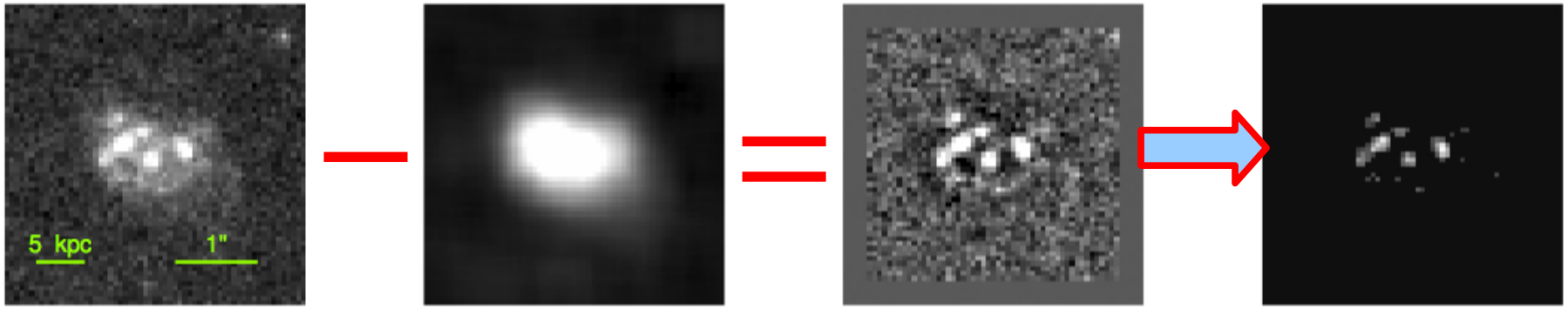
Sample

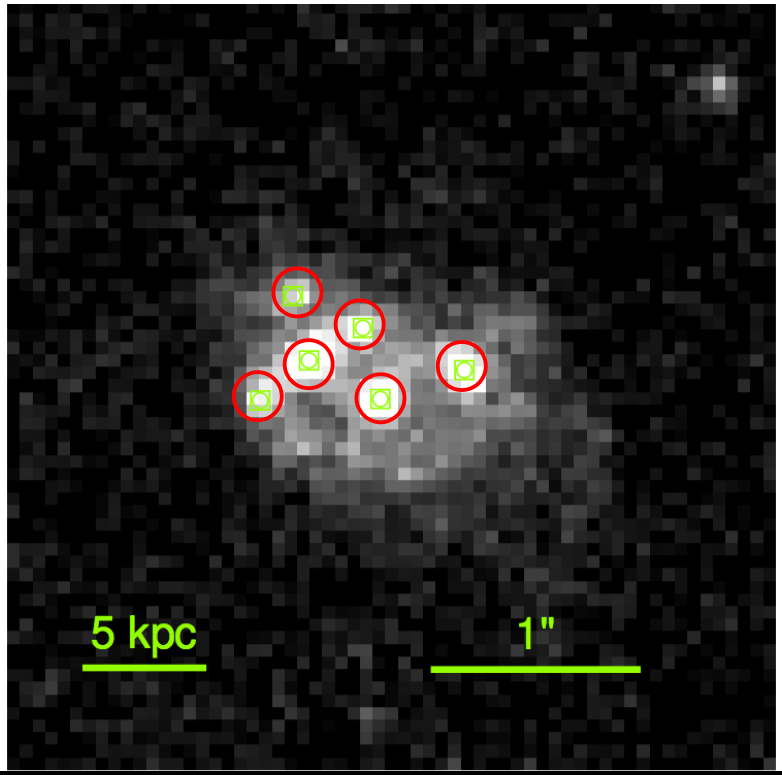
- GOODS-S and UDS
- 0.5 < z < 3
- log(M*) > 9
- SSFR > 0.1/Gyr
- q=b/a > 0.5
- Size (SMA) > 0.2”
- H < 24.5 AB



Blob Finder

Original Smoothed Contrast Filtered



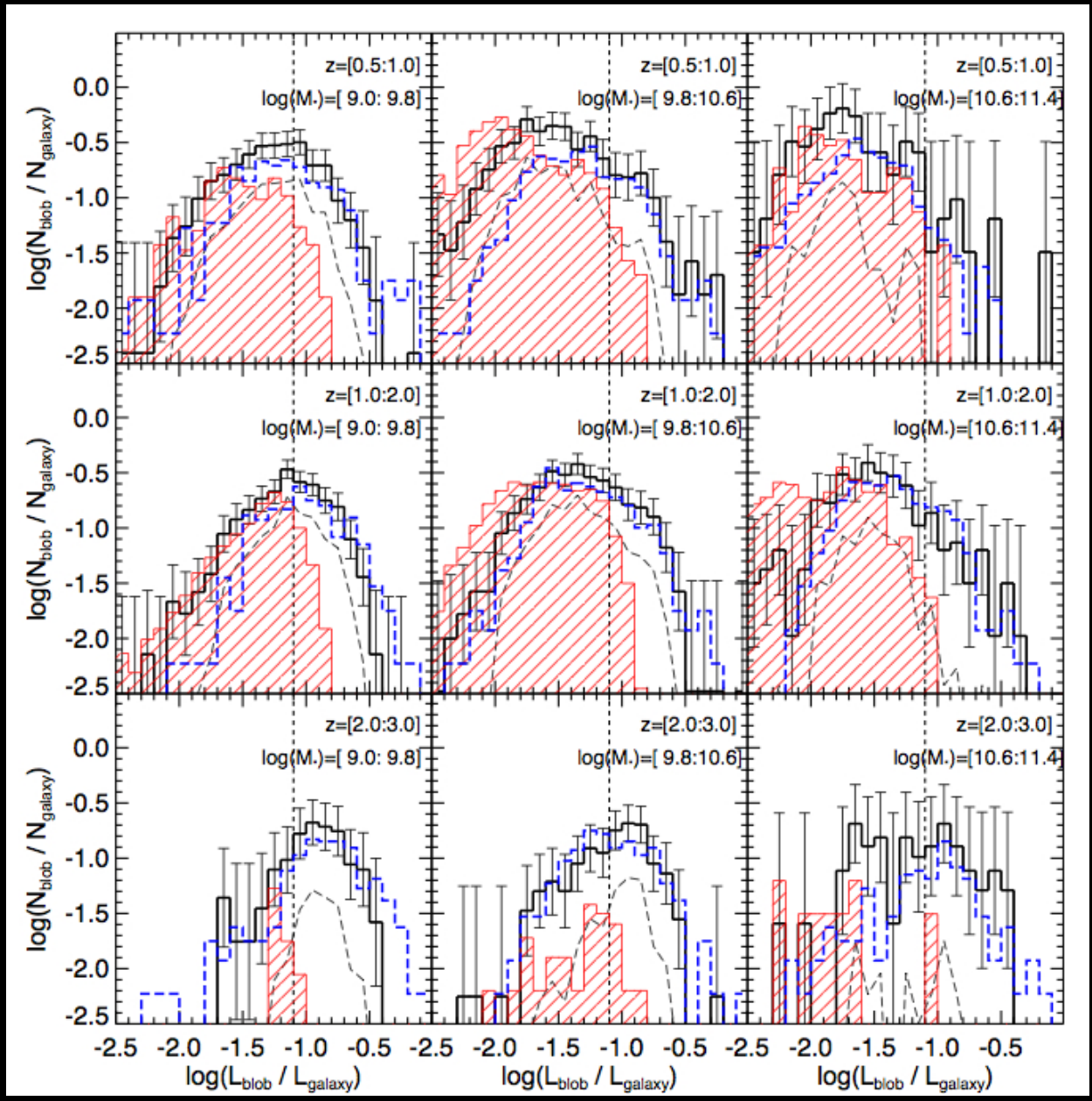


Detections are done in rest-frame UV wavelength

Defining Clumps

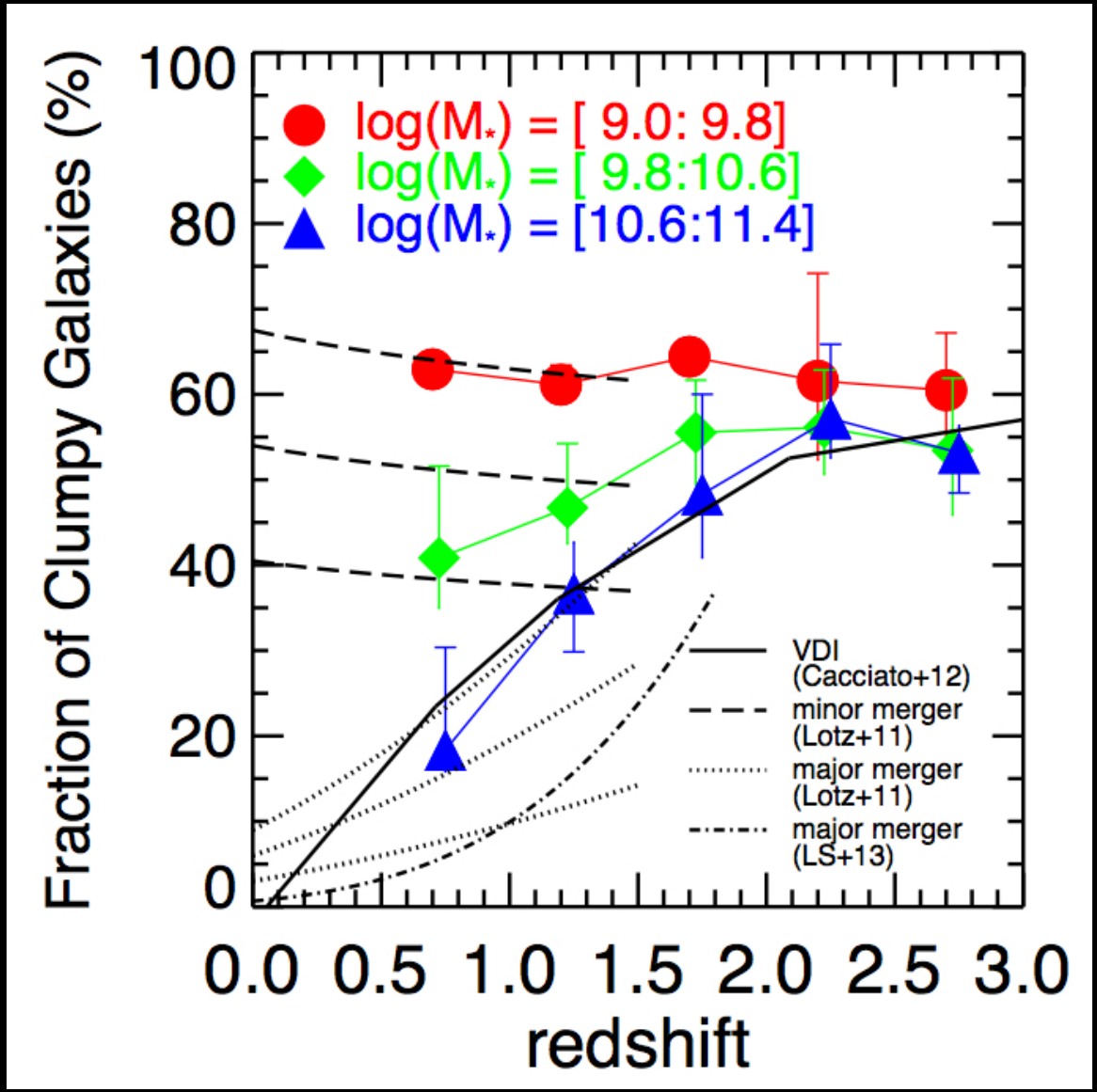
how nearby grand design spiral galaxies look at high redshift

- Clump: discrete star-forming region that contributes >8% of the total UV light of their galaxies
- Clumps defined in such way cannot be explained by the blending of nearby HII regions
- A more physical definition than the appearance of galaxies

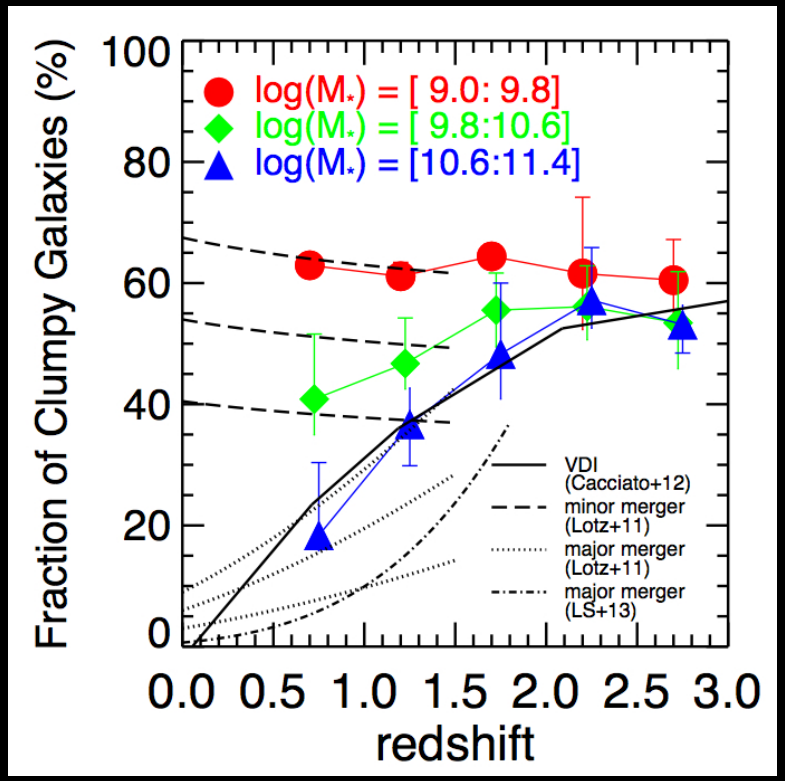


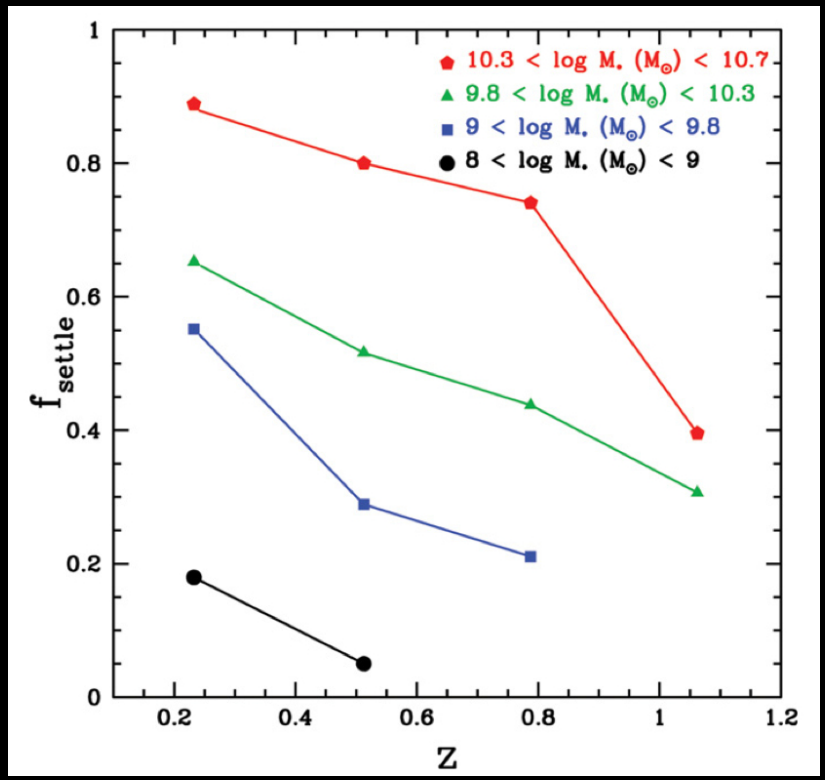
Possible Clump Formation Mechanisms

- VDI: the trend of its predicted sigma/v consistent with the clumpy fraction of massive galaxies
- Minor merger: merger fraction consistent with the clumpy fraction of intermediate-mass galaxies at z<1.5, given reasonable observability time-scale
- Major merger: unlikely be responsible for clump formation at z<1.5



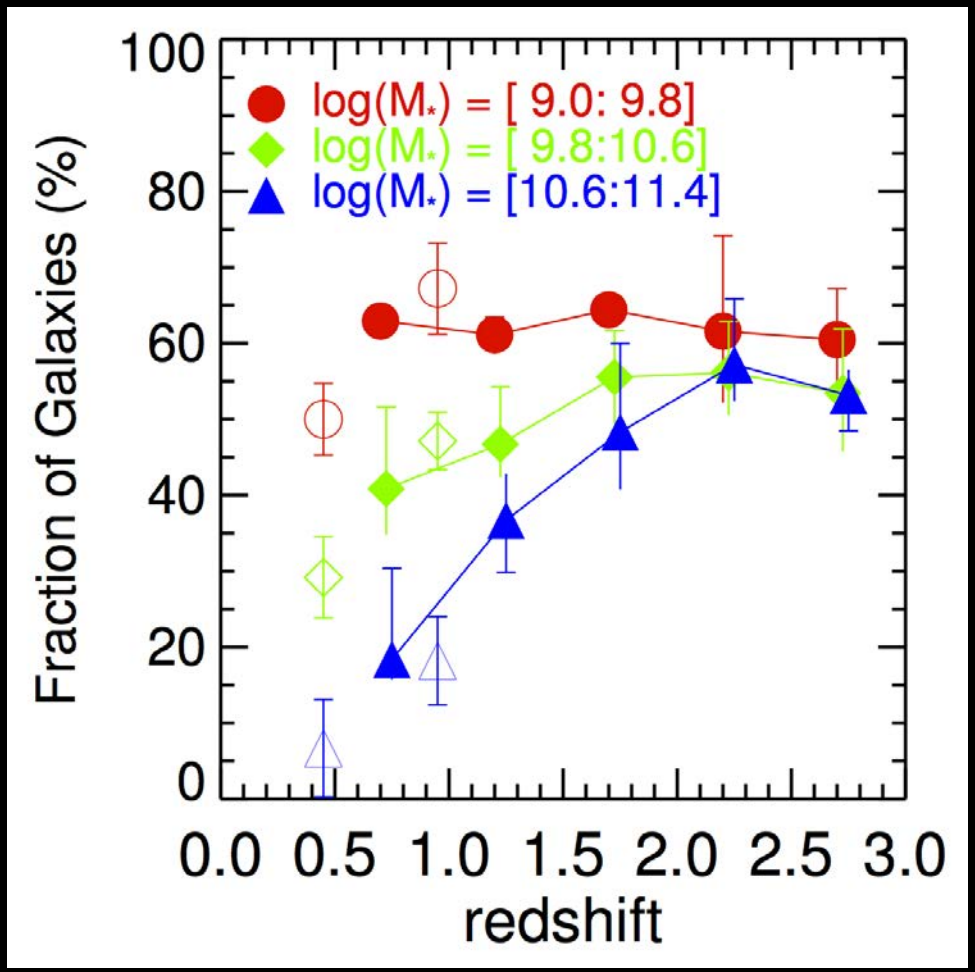
Part III: Connection between Clumps and Galaxy Kinematics at z~0.5



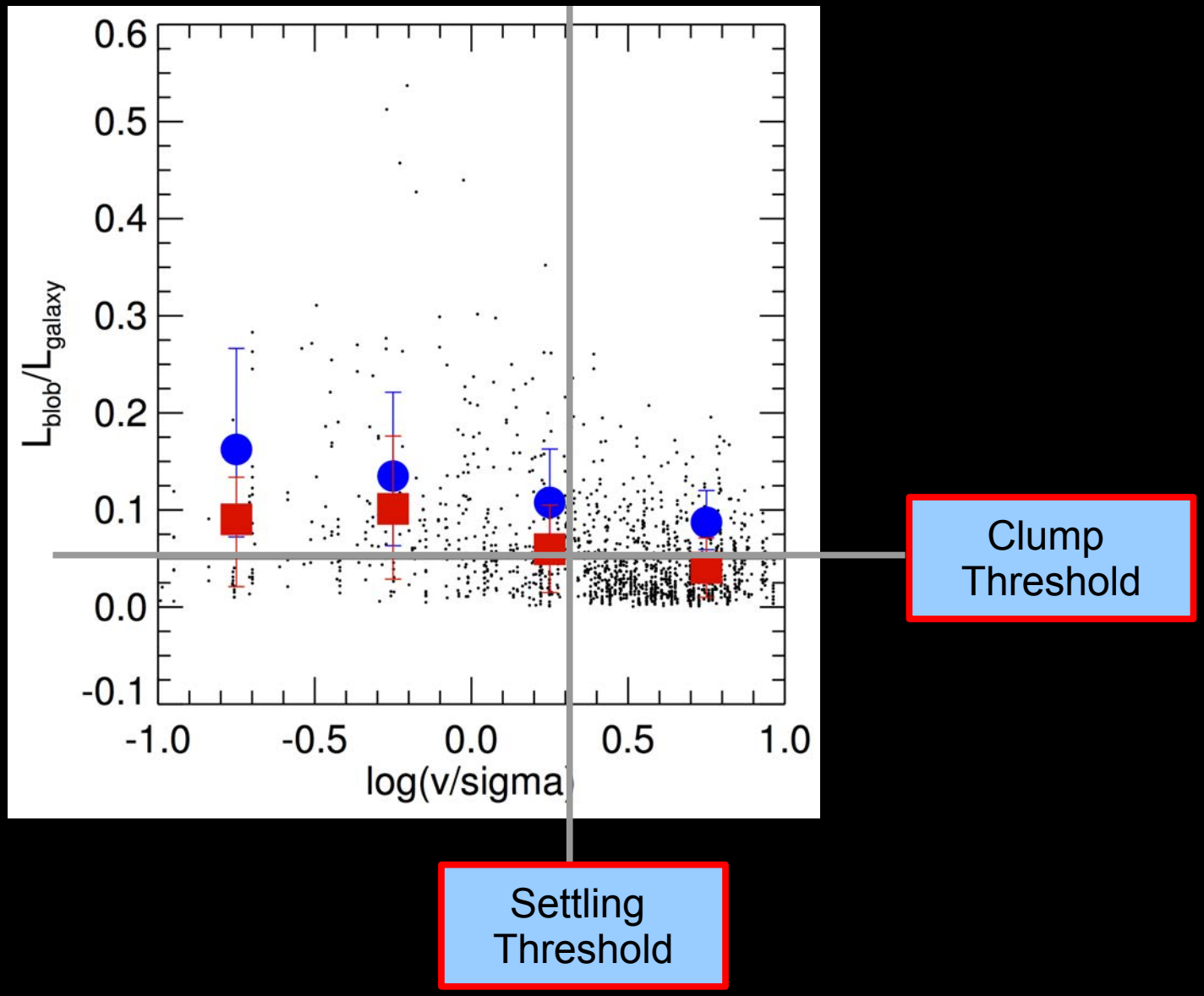


Kassin et al. (2012)

Settled fraction is consistent with clumpy fraction



Clumps found in unsettled galaxies are UV-brighter



Summary: tracing clumpy galaxies from z=3 to z=0.5

- Physical properties of clumps and their variations at z~2
  (1) Clumps are blue regions with enhanced sSFR
  (2) Central clumps are redder, and outskirts clumps are bluer
  (3) Clump's radial variation is consistent with the in-ward migration scenario

- Clumpy fraction of star-forming galaxies from z=3 to z=0.5
  (1) Need a physical definition of clumps
  (2) Propose a definition based on the fractional luminosity of clumps
  (3) About 60% of star-forming galaxies at z~3 are clumpy
  (4) The evolution of the clumpy fraction depends on the mass of the galaxies: the more massive the galaxies, the faster the clumpy fraction drops with the cosmic time

- Connection between clumps and galaxy kinematics at z~0.5
  (1) Settled disk fraction consistent with clumpy fraction
  (2) Clumps in unsettled galaxies are brighter (in UV) than those in settled galaxies