Modeling the Evolution of Compact Star-Forming Galaxies

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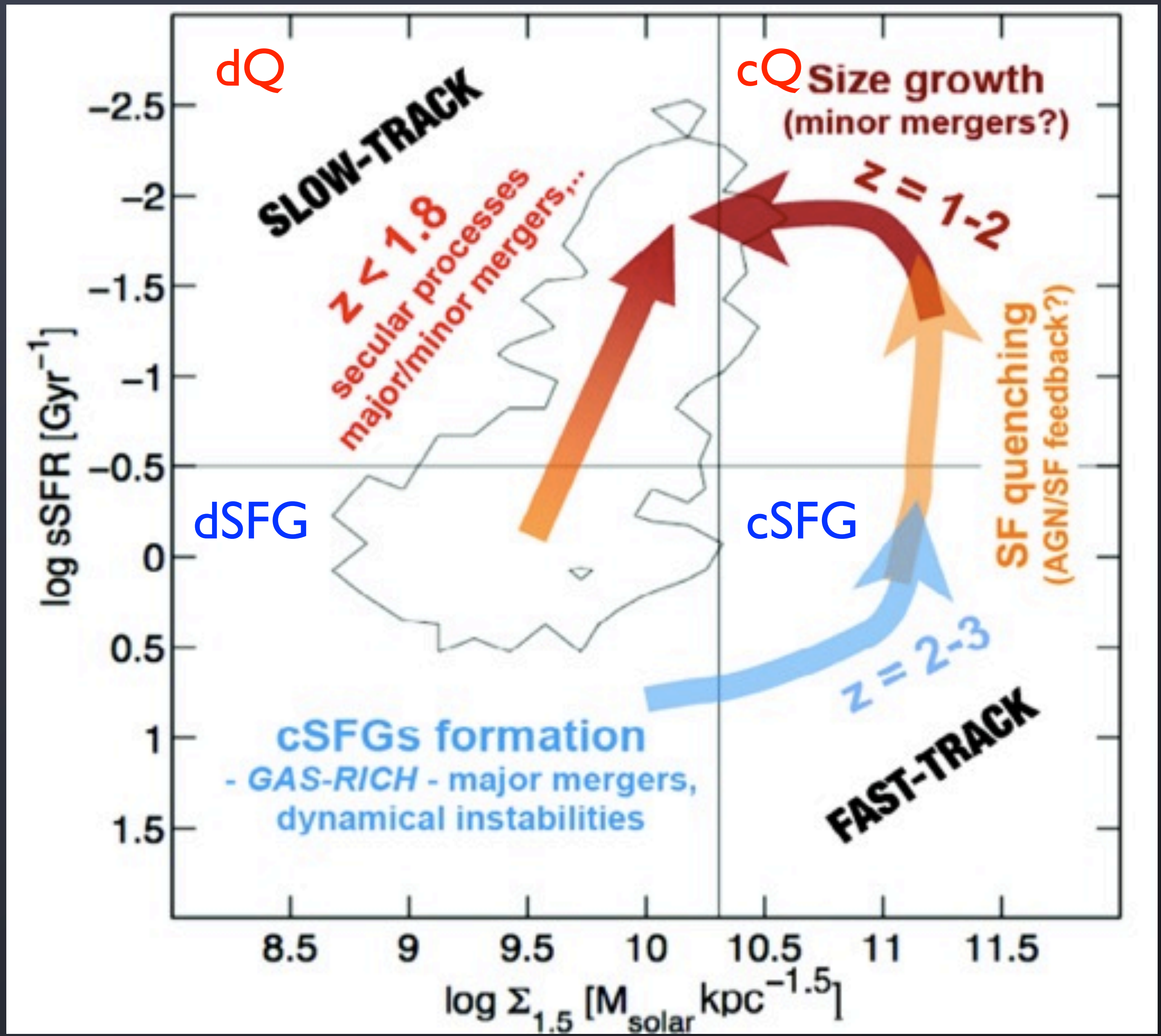
Red and Blue Nuggets

- Barro et al. (2012) propose a ‘red sequence fast track:’
- ~20% of high-redshift diffuse SFG become compact SFG. These galaxies quench rapidly, followed by a slower growth in size.
- Transition from diffuse to compact triggered by gas-rich processes- major mergers, or dynamical instabilities.
- How well does the SAM recreate this process?



Barro et al. (2012)

The Semi-Analytic Model

- Based off the Somerville et al. (2008, 2012) SAM. Major improvements include:
  - Running on the halo merger tree provided by the state-of-the-art Bolshoi simulation, with a WMAP 7 cosmology
  - Preservation of disks in gas-rich major mergers (Hopkins et al. 2009)
  - Formation of (pseudo)bulges through disk instabilities
  - **Full treatment of the growth of elliptical galaxies through major and minor mergers, including dissipative losses due to star formation**

Building the Model: Predicting Stellar Radii and Velocity Dispersions for Elliptical Galaxies

- Observations and high-resolution simulations have shown that major mergers of gas-rich spirals induce massive amounts of star formation, typically consuming most of the gas from the progenitor galaxies (Dekel & Cox 2006, Robertson et al. 2006, Wuyts et al. 2010).
  - Star formation → energy lost due to dissipation

- Covington et al. (2008, 2011): including dissipation naturally reduces the sizes of elliptical galaxies, accounting for the smaller and steeper size-mass relation.

- Parameters calibrated to results of GADGET (Cox et al. 2006, Johansson et al. 2009) binary merger simulations. Relative importance of dissipation and internal energy characterized by C_{dissip}/C_{int}.
  - Major disk-disk mergers: $C_{dissip}/C_{int} = 3.1$
  - Minor disk-disk mergers: $C_{dissip}/C_{int} = 1.1$
  - All other mergers: $C_{dissip} = 0.0$

- Model velocity dispersion using the virial theorem, including a contribution from dark matter within 1 R_e.

Building The Model: Predictions

- Gas-poor ‘dry’ mergers increase the radii of the remnants

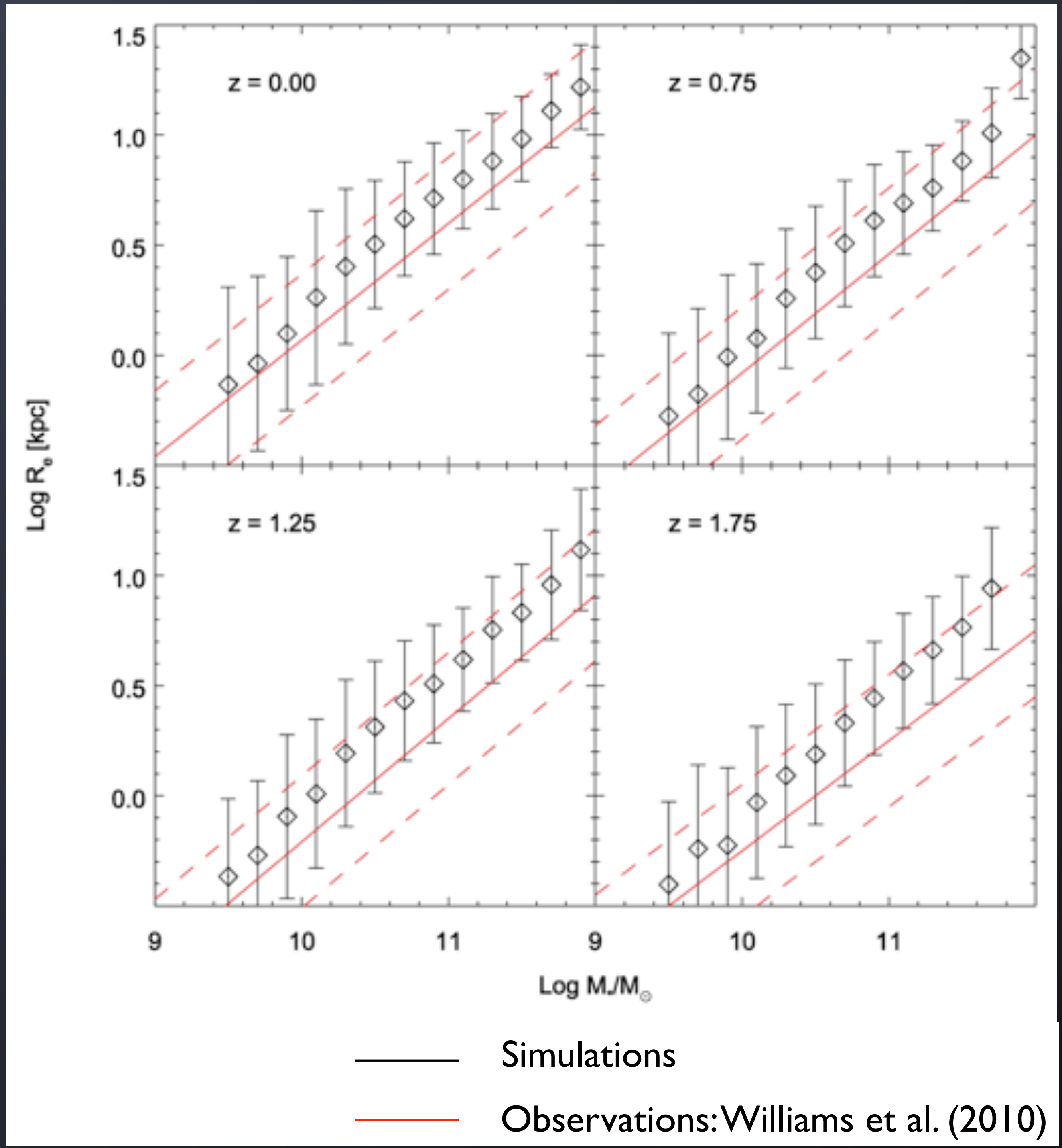
- Gas-rich ‘wet’ mergers produce remnants with similar or smaller radii as their progenitors

- Gradient in gas fraction with stellar mass can introduce a tilt in the FP and account for the steepening of the size-mass relation from disks to ellipticals.

- *Treat disk instabilities as mergers.*

Building the model: Results

- Compared to the progenitors, remnants are:
  - More compact
  - Steeper size-mass relation
  - Greater evolution with redshift
  - Smaller dispersion in size-mass relation
- Subsequent minor mergers increase the effective radius and the scatter in radius while leaving the velocity dispersion relatively unchanged (Naab et. al 2009, Oser et al. 2012).



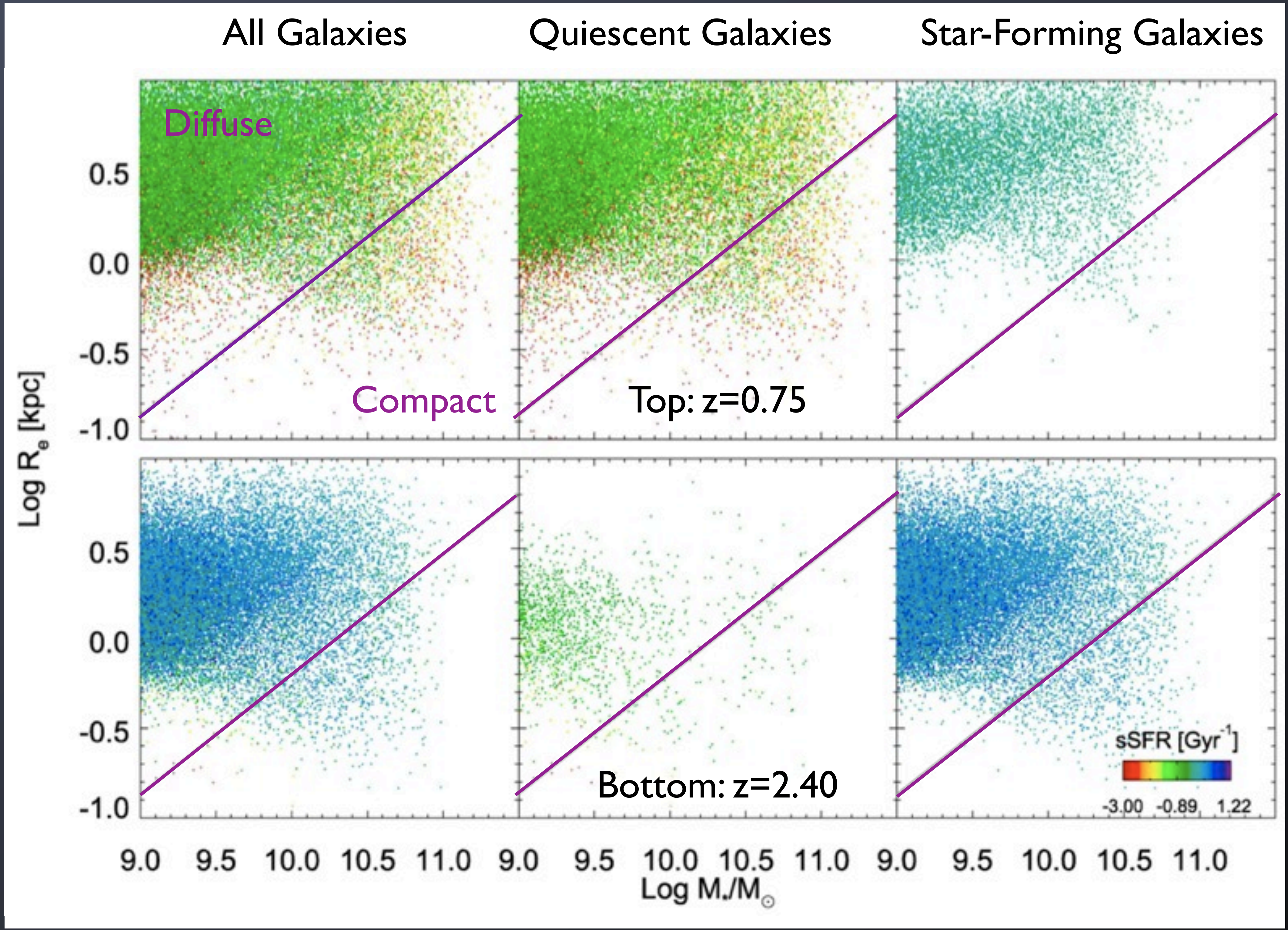
Red and Blue Nuggets

- Select all galaxies with $M_* > 10^{10}\ M_\odot$ at the desired redshift
- Define compactness as $\Sigma_\alpha = M_*/r_e^\alpha$, $\alpha=1.5$
    - Effective radius is mass-weighted average of disk and bulge half-mass radii
- log sSFR [Gyr^{-1}] = -0.5 separates quiescent (Q) from star-forming (SF) galaxies
- Σ_α = 10.3 separates compact (c) from diffuse (d) galaxies

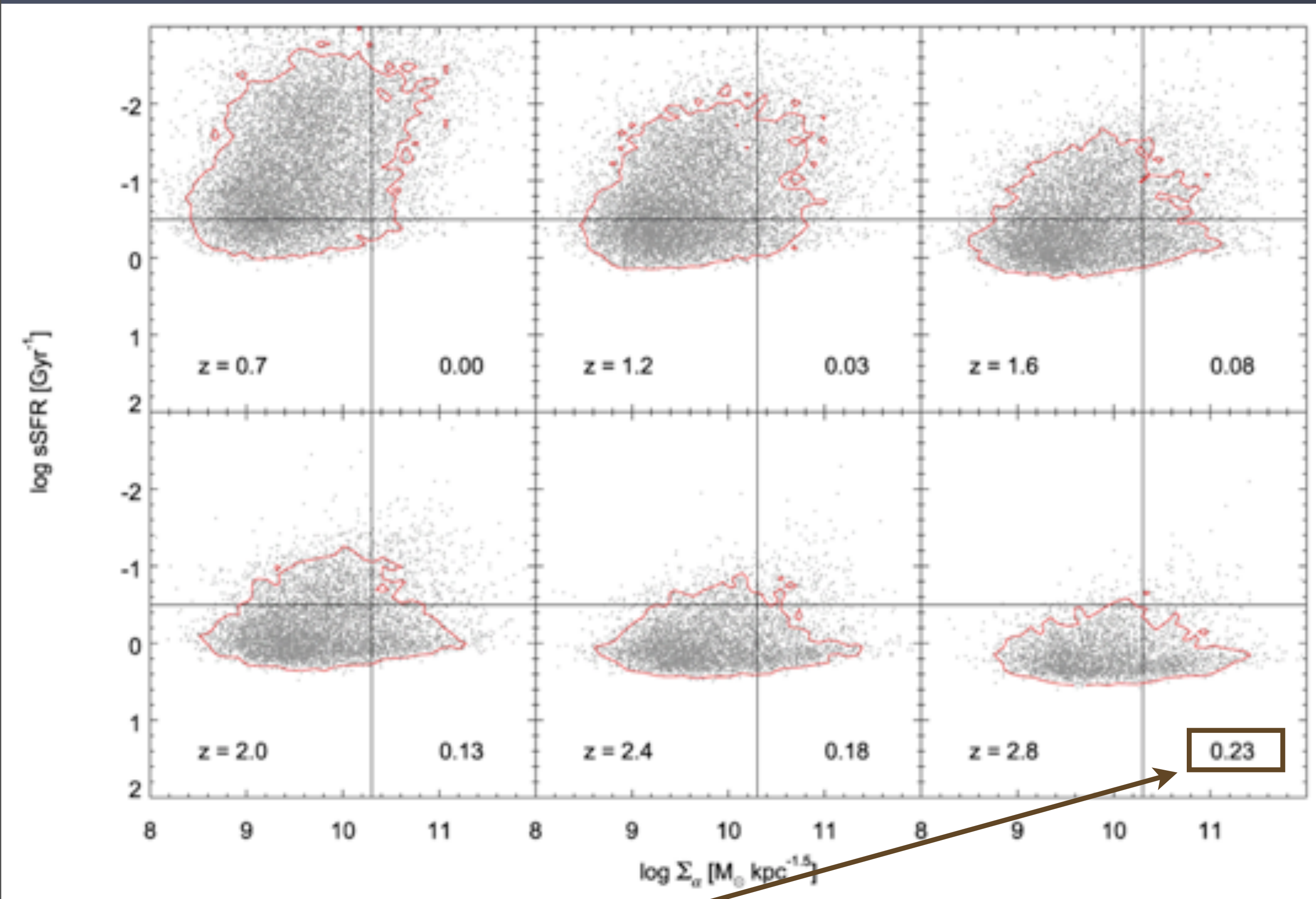
Red and Blue Nuggets

Most compact galaxies are quiescent at low redshifts ('red nuggets')

Most compact galaxies are star-forming at high redshifts ('blue nuggets')



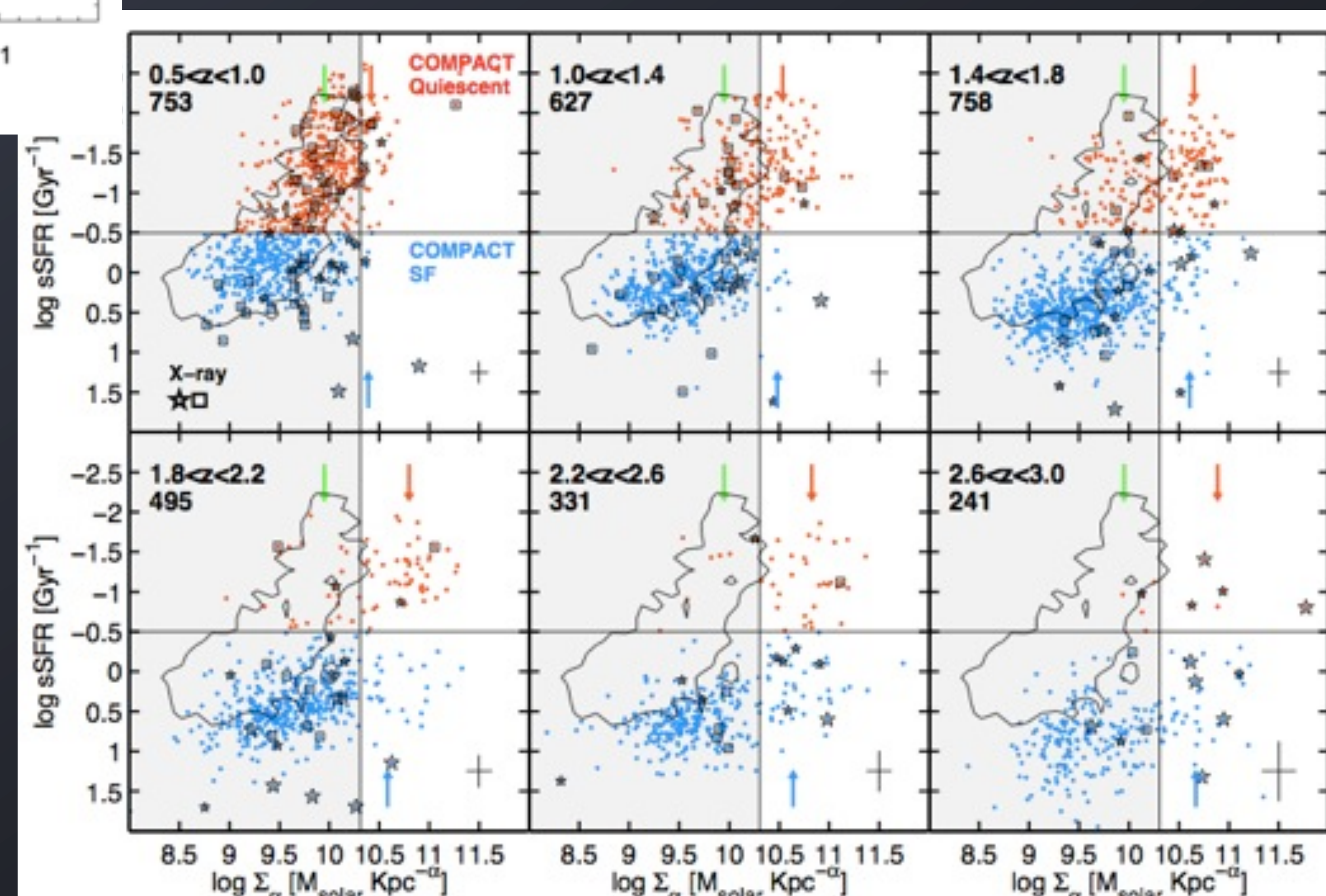
Red and Blue Nuggets



Simulations

- •Theory and observations are qualitatively similar. However, simulated dSFG have lower sSFR than the observations while simulated low-redshift diffuse galaxies have lower surface densities.

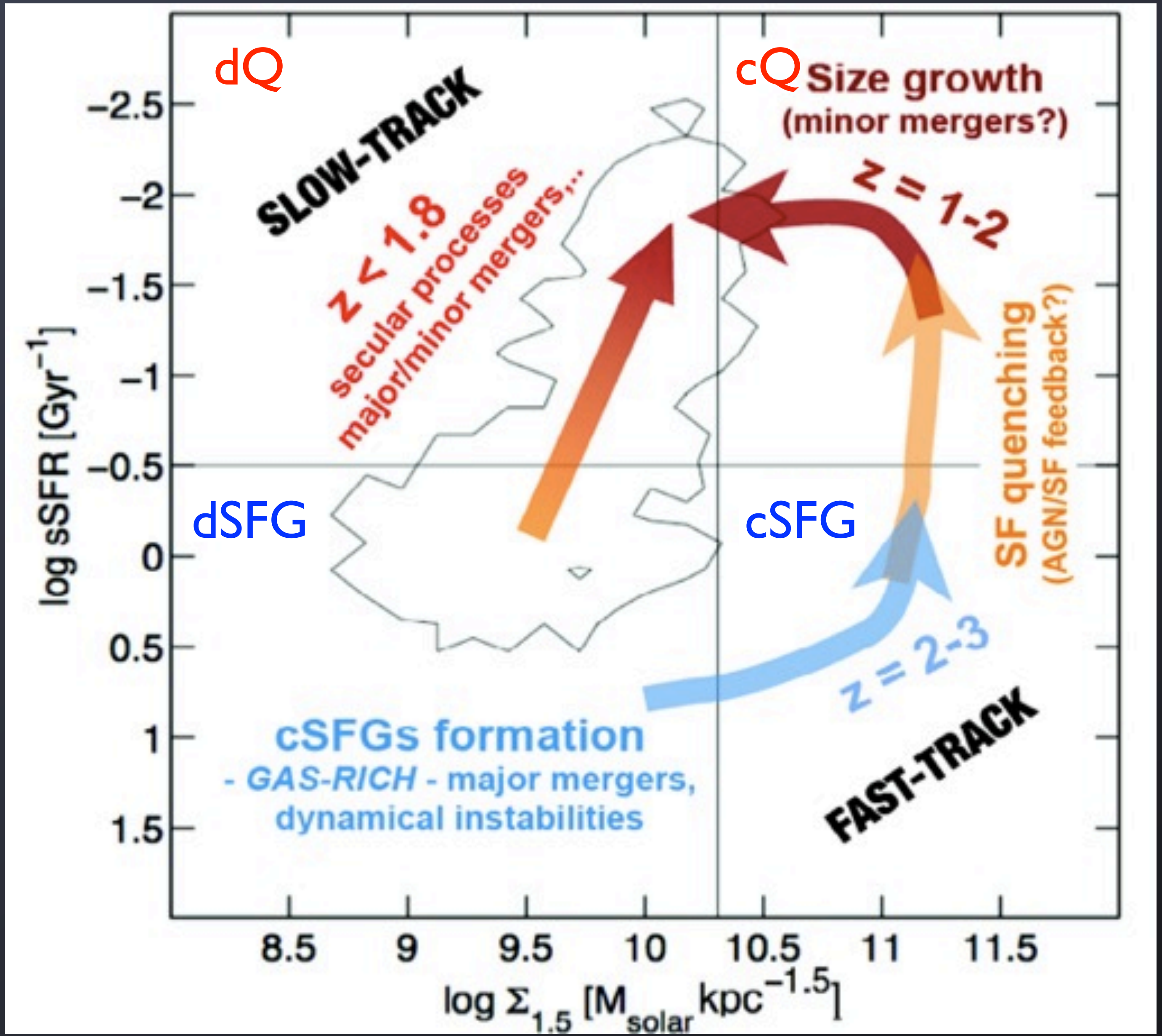
- •23% of galaxies at z=2.8 are cSFG, compared to ~20% in observations
- •Number density declines with redshift, in agreement with observations



Barro et al. (2012)

Red and Blue Nuggets

- What happens to diffuse SFG at z=2.8?
  - Most are quiescent and diffuse (dQ) below z~1.7
  - ~10% become cSFG between z=2.4 and z=1.6
- What happens to compact SFG at z=2.4?
  - Most are quiescent and compact (cQ) below z~1.7
  - Increase in fraction of diffuse quiescent (dQ) galaxies below z=1.4



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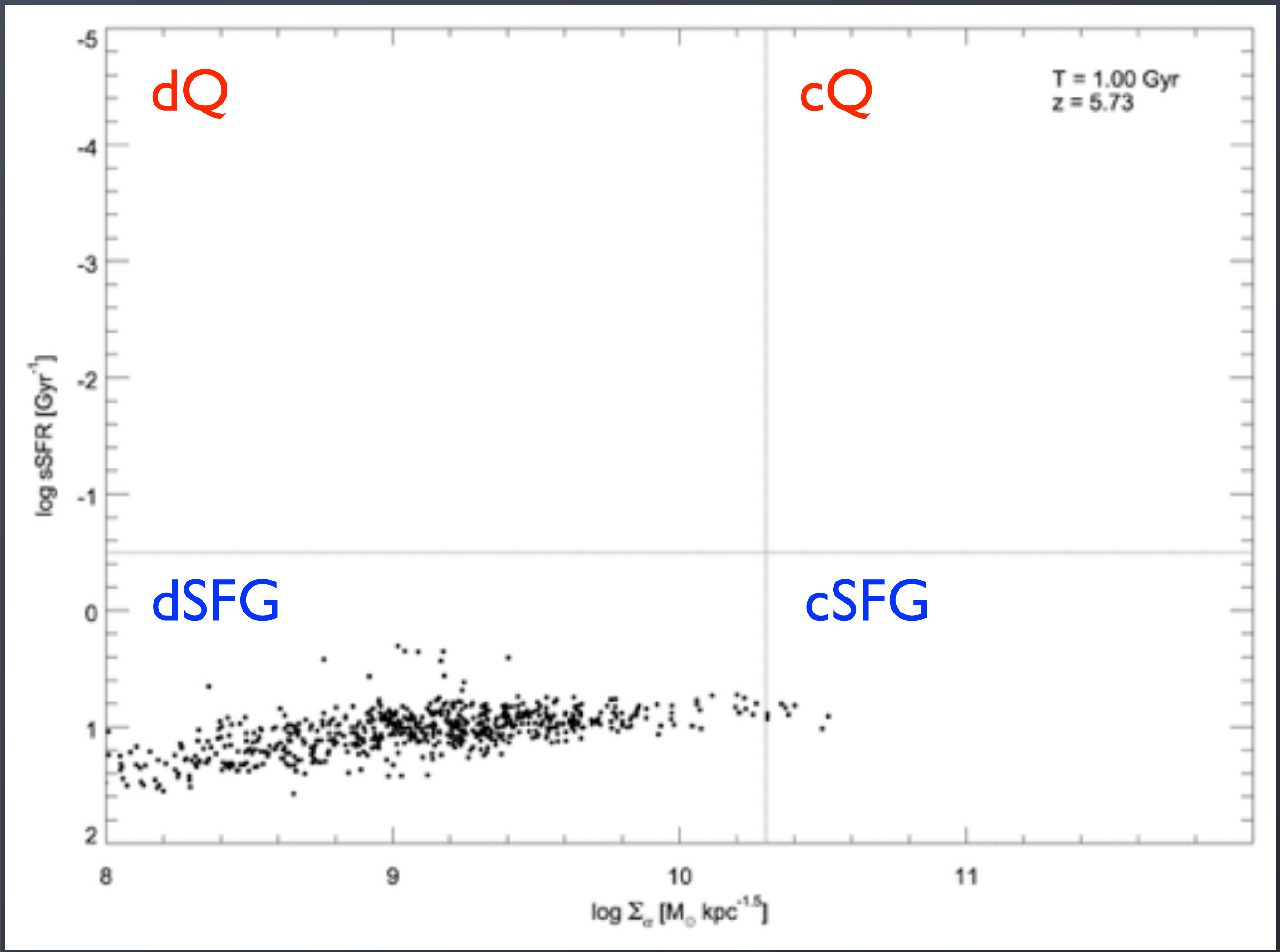
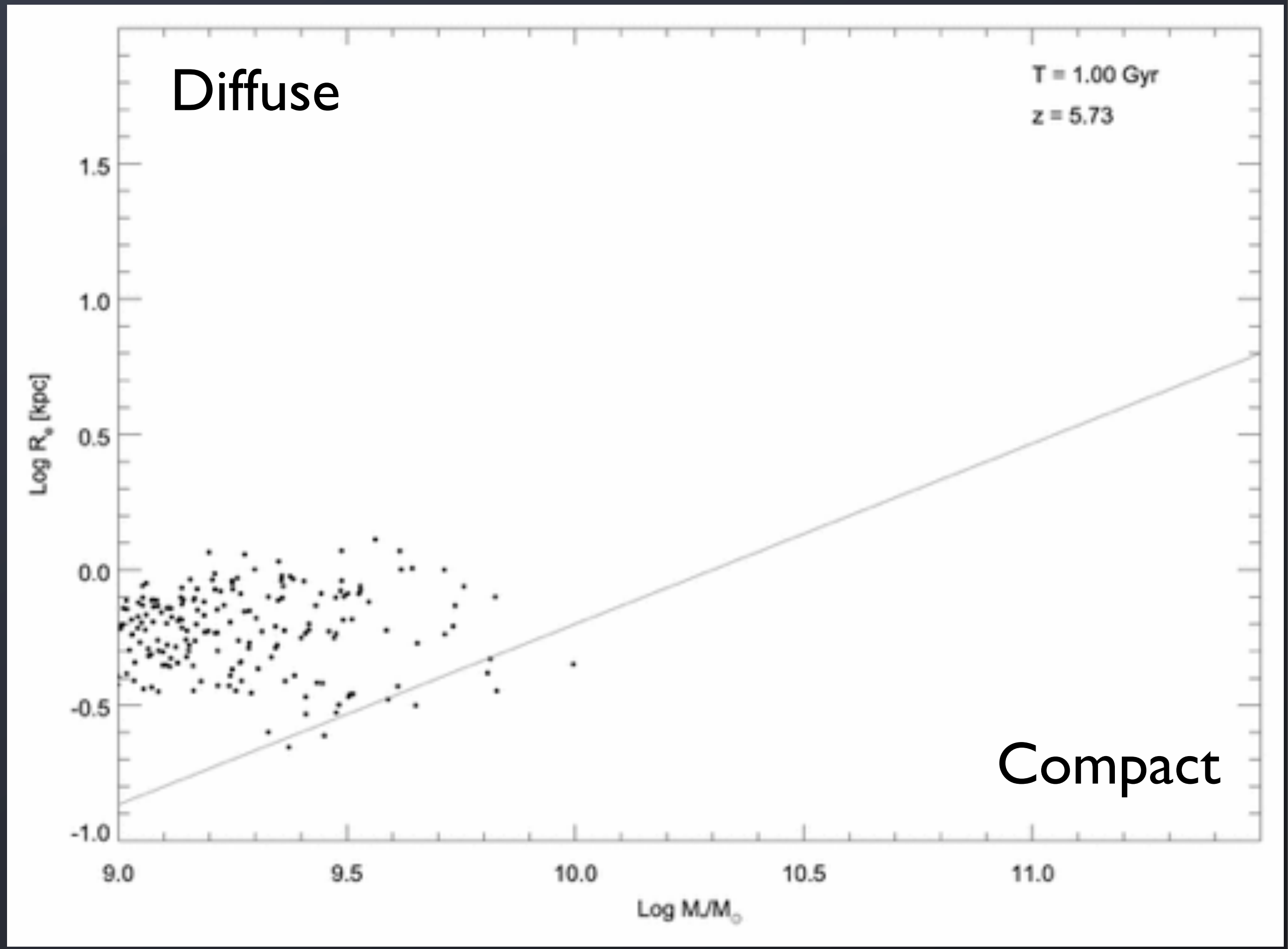
Red and Blue Nuggets

cSFG at z = 2.4





Gas-rich merger in past Gyr

Gas-poor merger in past Gyr

Red and Blue Nuggets

- **How important are major mergers in forming cSFG?**
- Of cSFG at z=2.8:
  - 11% have had a major merger in the past Gyr (vs 15% of dSFG)
  - 80% have never had a major merger (vs 74% of dSFG)
  - 44% have had a major or minor merger in the past Gyr (vs 53% of dSFG)
  - 28% have never had a major or minor merger (vs 23% of dSFG)

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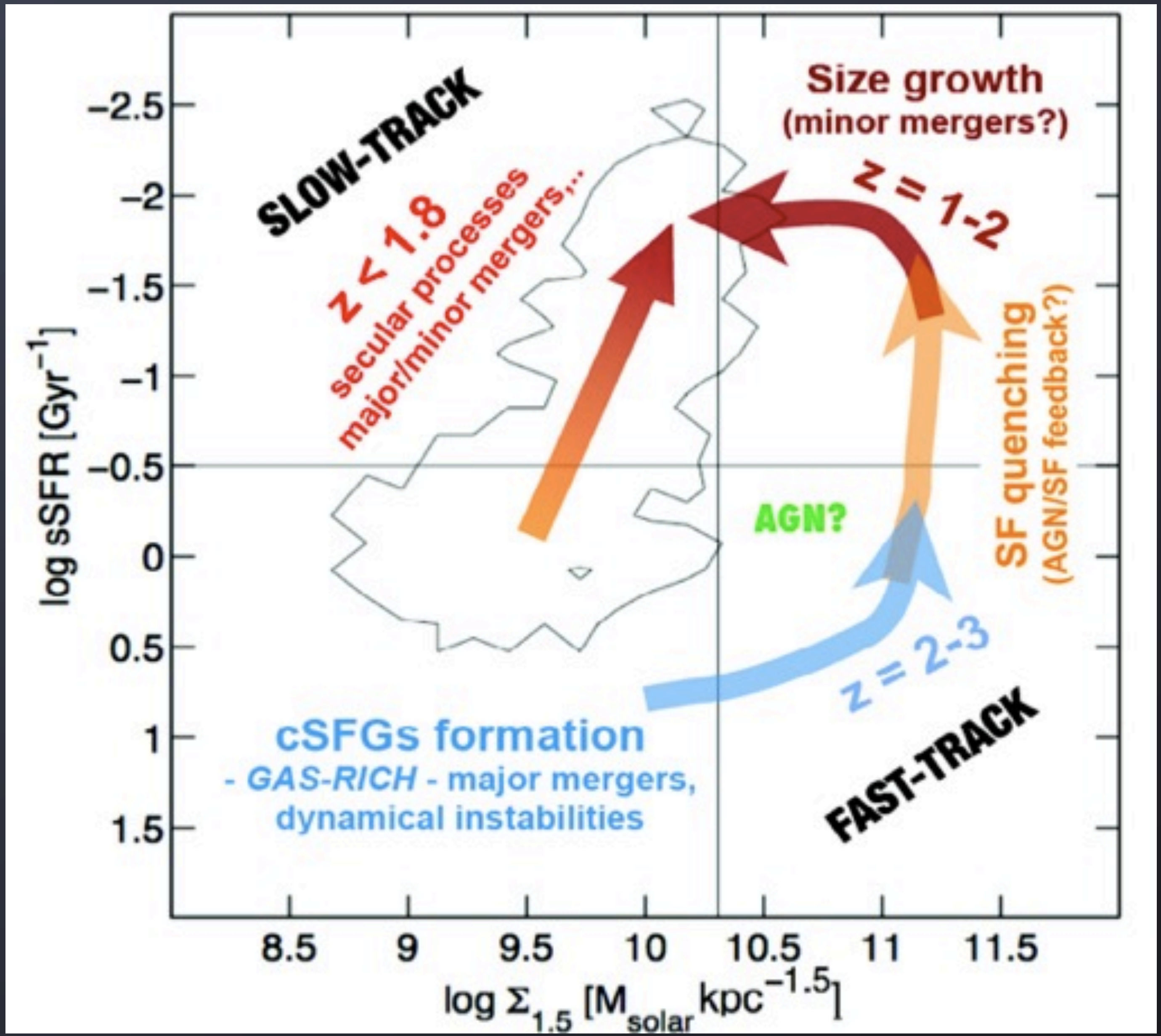
➡ Minor mergers and disk instabilities have a large contribution to the population of cSFGs at high redshift

Summary

SAM Conclusions

- Galaxies move from dSFG to cSFG through gas-rich major and minor mergers, as well as classical disk instabilities. Major mergers may *not* be the dominant mechanism for creating compact galaxies.
- Diffuse and compact SFG may quench at similar redshifts, z ~ 1.5-1.7
- Minor mergers decrease the surface density of cSFG, but most remain compact down to redshift 0
- Caveat: outstanding questions about SAM treatment of disk instabilities



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