Observations of star formation at z=1-3

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Star formation in young galaxies

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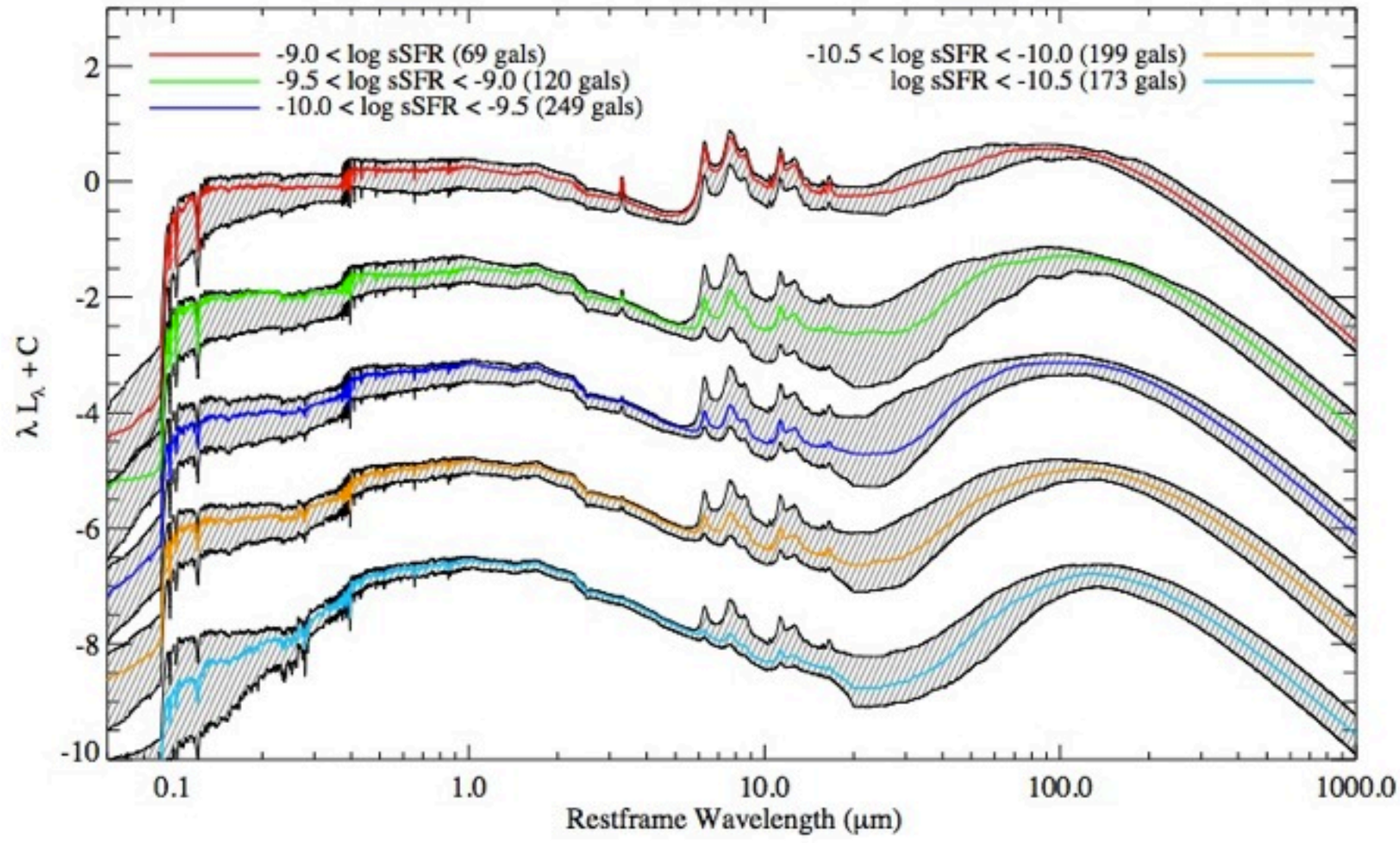
Some theoretical and observational reasons are given for regarding star formation as an induced process that proceeds in a series of bursts triggered by dynamical events, and it is suggested that intense bursts of star formation may have been particularly important for the early evolution of elliptical galaxies.

Measuring star formation

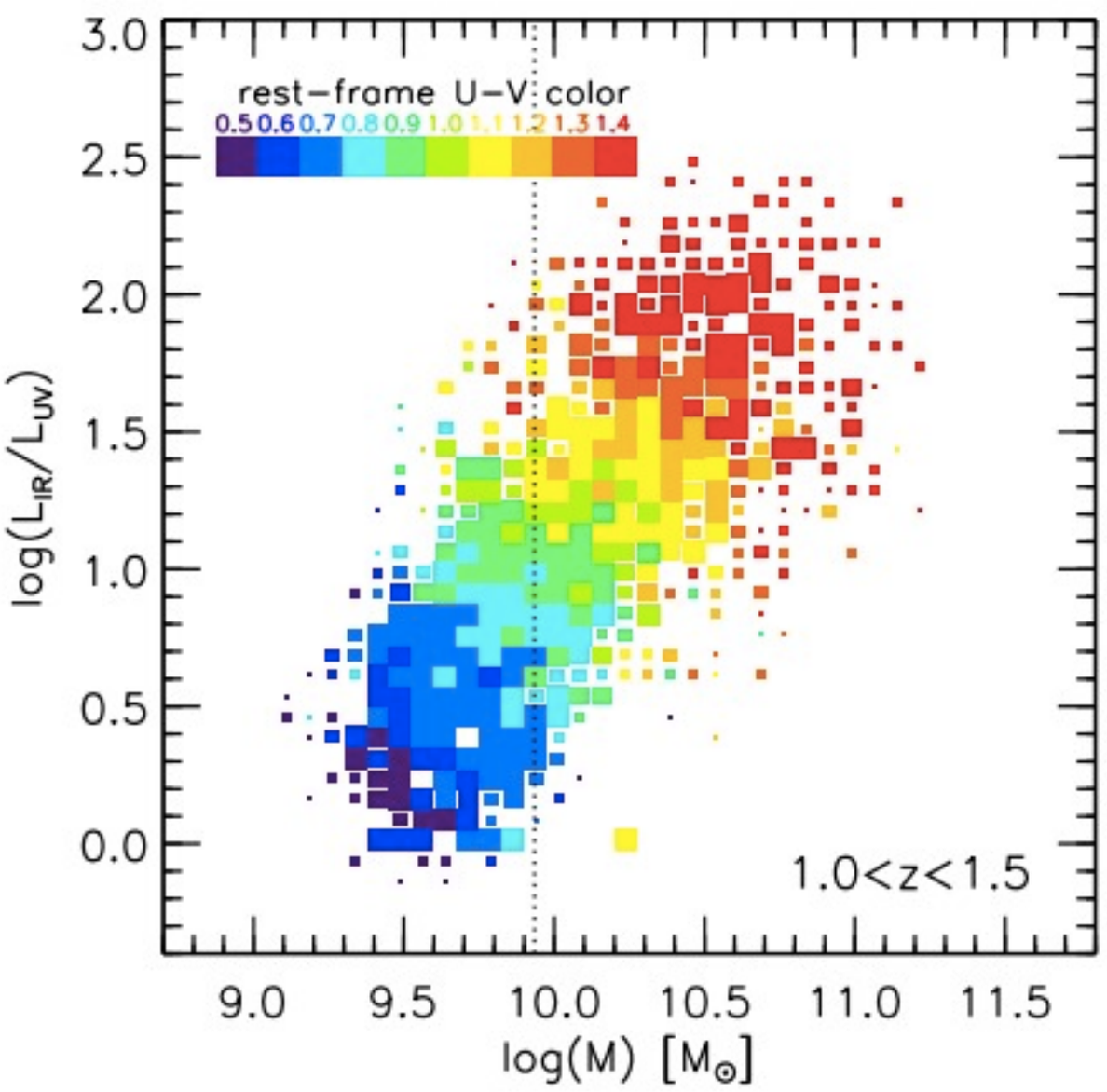
- Until recently: UV emission + dust correction
- Thanks to MIPS, Herschel: bolometric L



Smith et al 2012

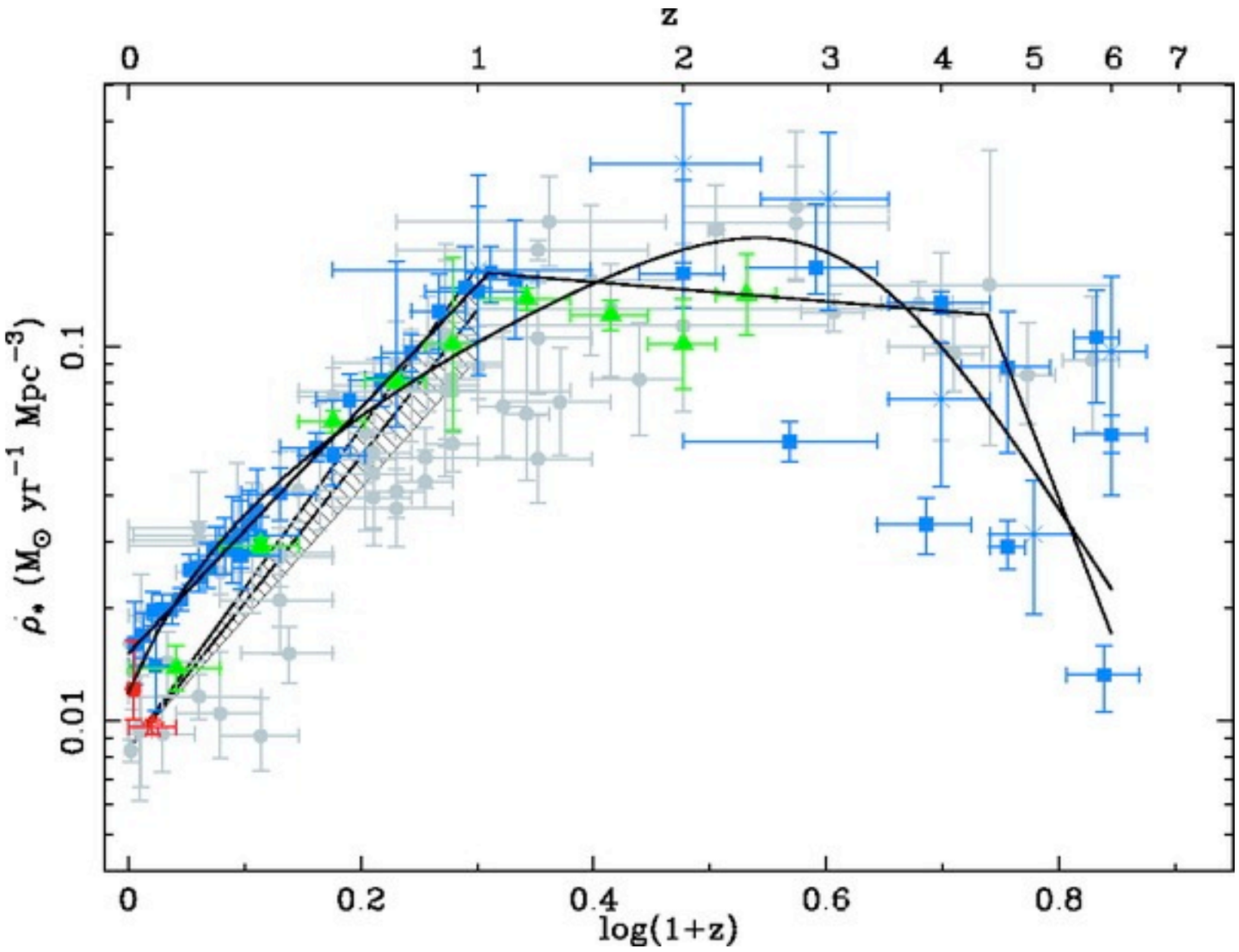
Measuring star formation

- Measuring IR luminosity important - particularly for massive galaxies



Whitaker et al 2012

Cosmic star formation history

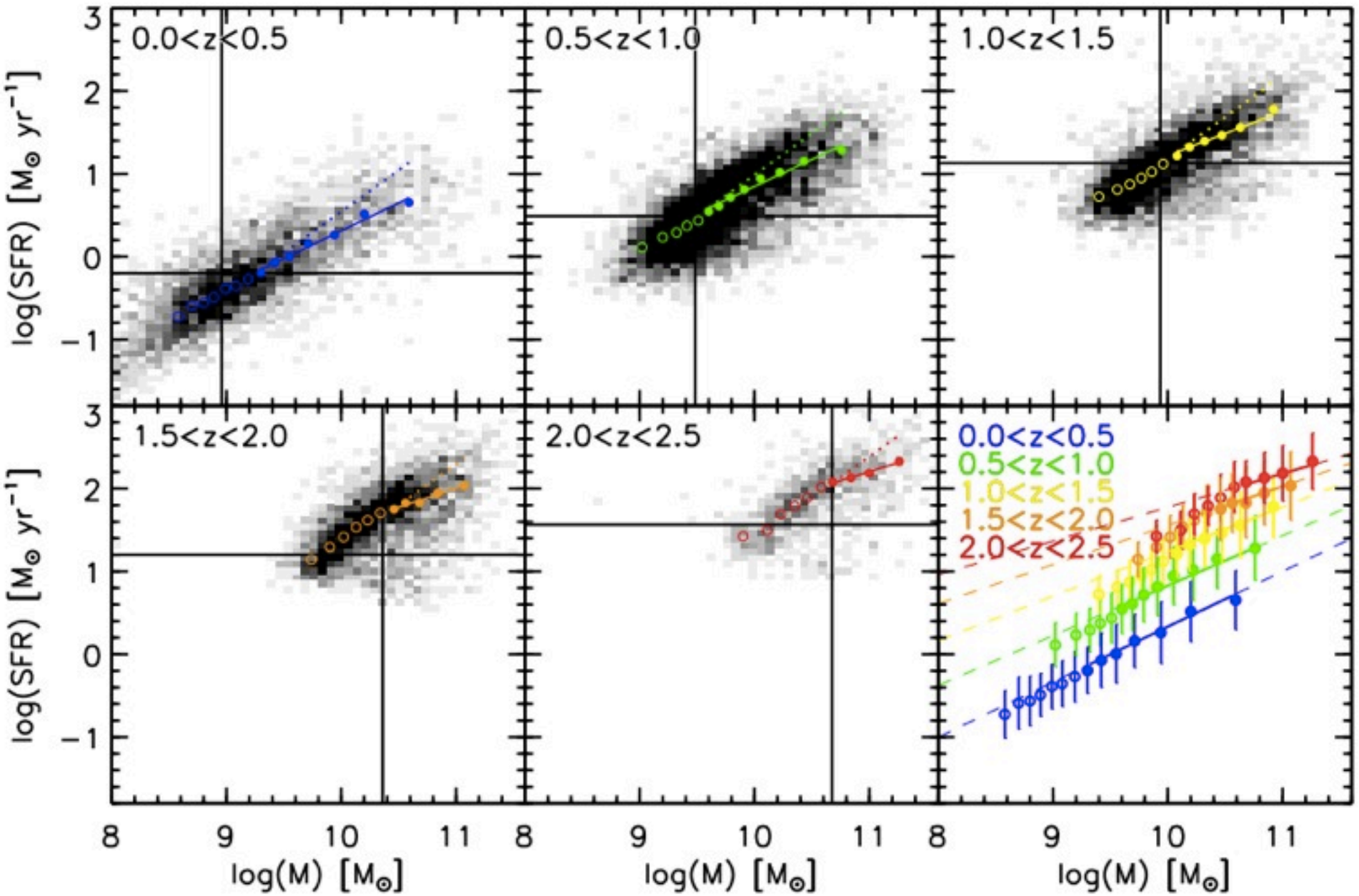


Hopkins & Beacom 2006;
Bouwens et al 2008-20

- Broad peak at z=1-3: formed about 50% of stars
- Cosmic star formation rate 10x higher than today

Peak of the star formation history

- Question: were there more star forming galaxies, or did individual galaxies have higher rates ?
- Need to study individual galaxies rather than cosmic averages



Whitaker et al 2012; also Noeske et al 2007, Zheng et al 2008, Damen et al 2009, etc

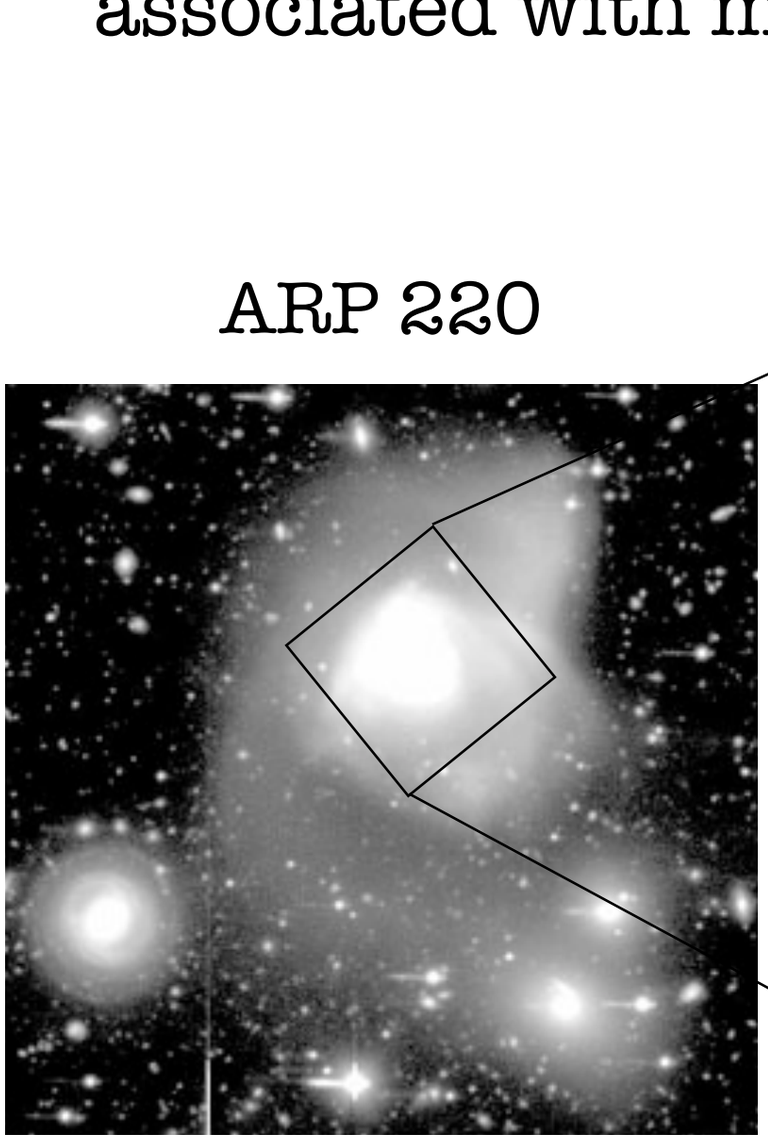
Peak of the star formation history

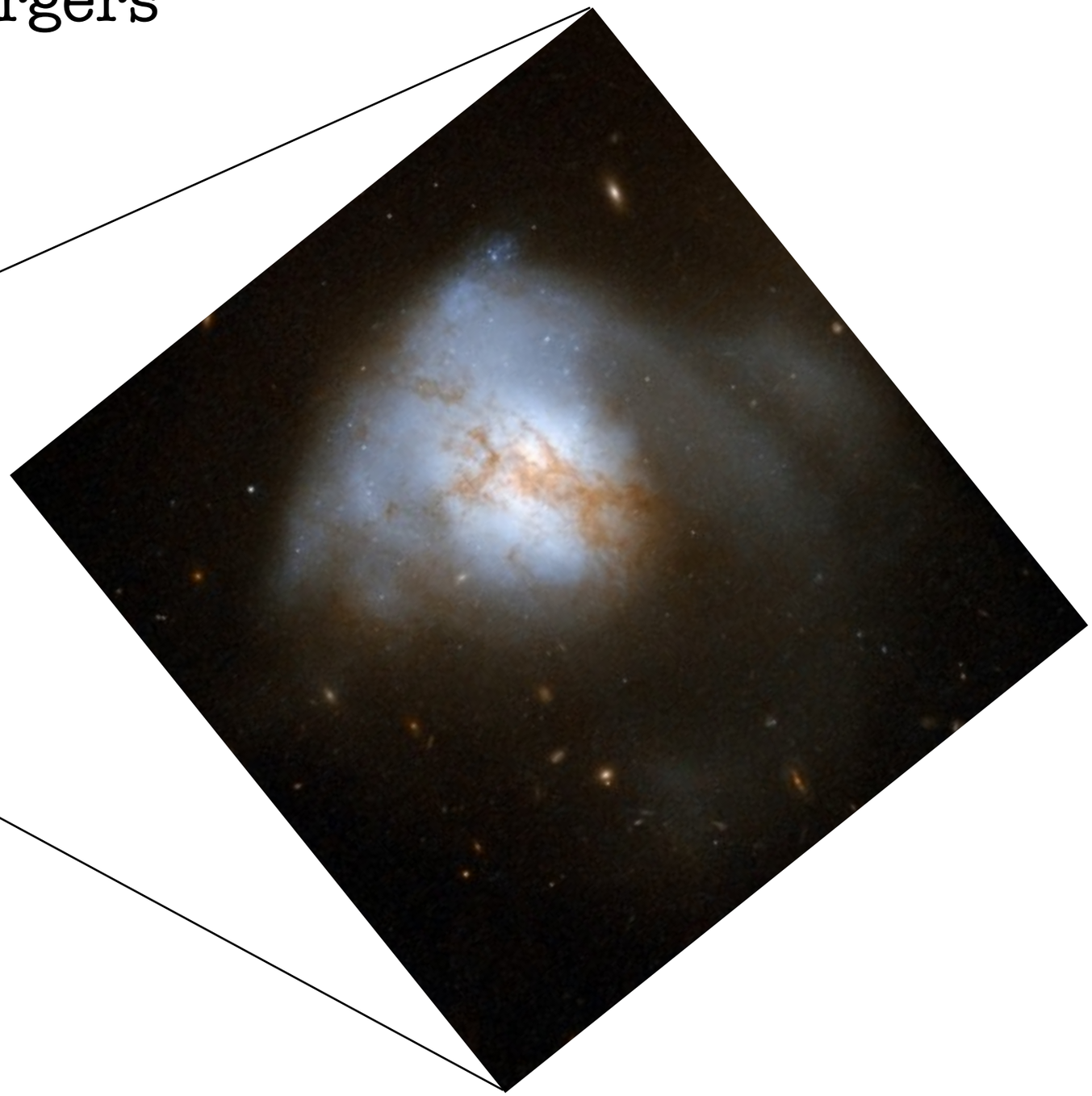
- Question: ~~were there more star forming galaxies,~~ or did individual galaxies have higher rates ?

Nature of star forming galaxies

- In the local Universe, high SFRs typically associated with mergers

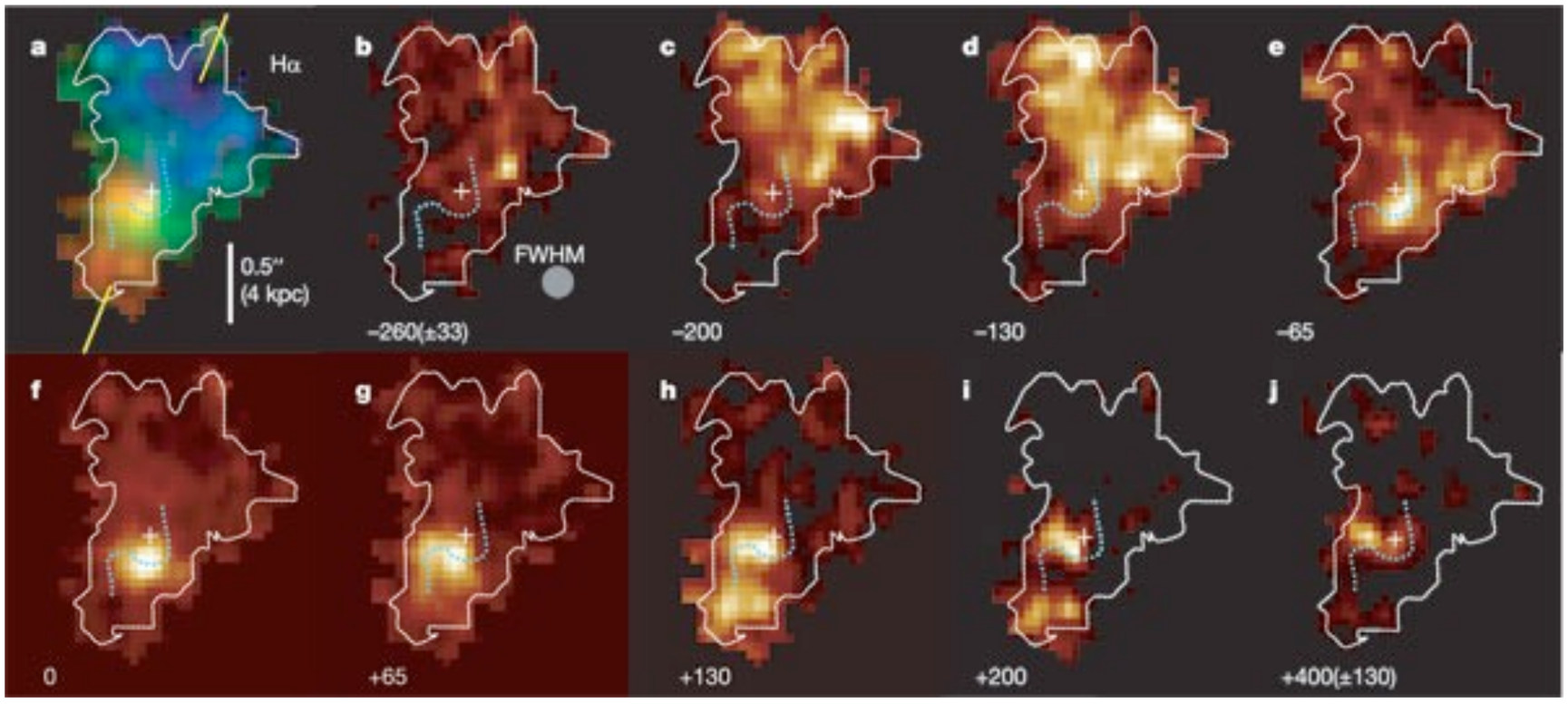
ARP 220





Nature of star forming galaxies

- At high redshift at least some, and apparently most, strong star formation occurs in disks



Apparently rotating gas disk at z=2.4 (Genzel et al 2006)

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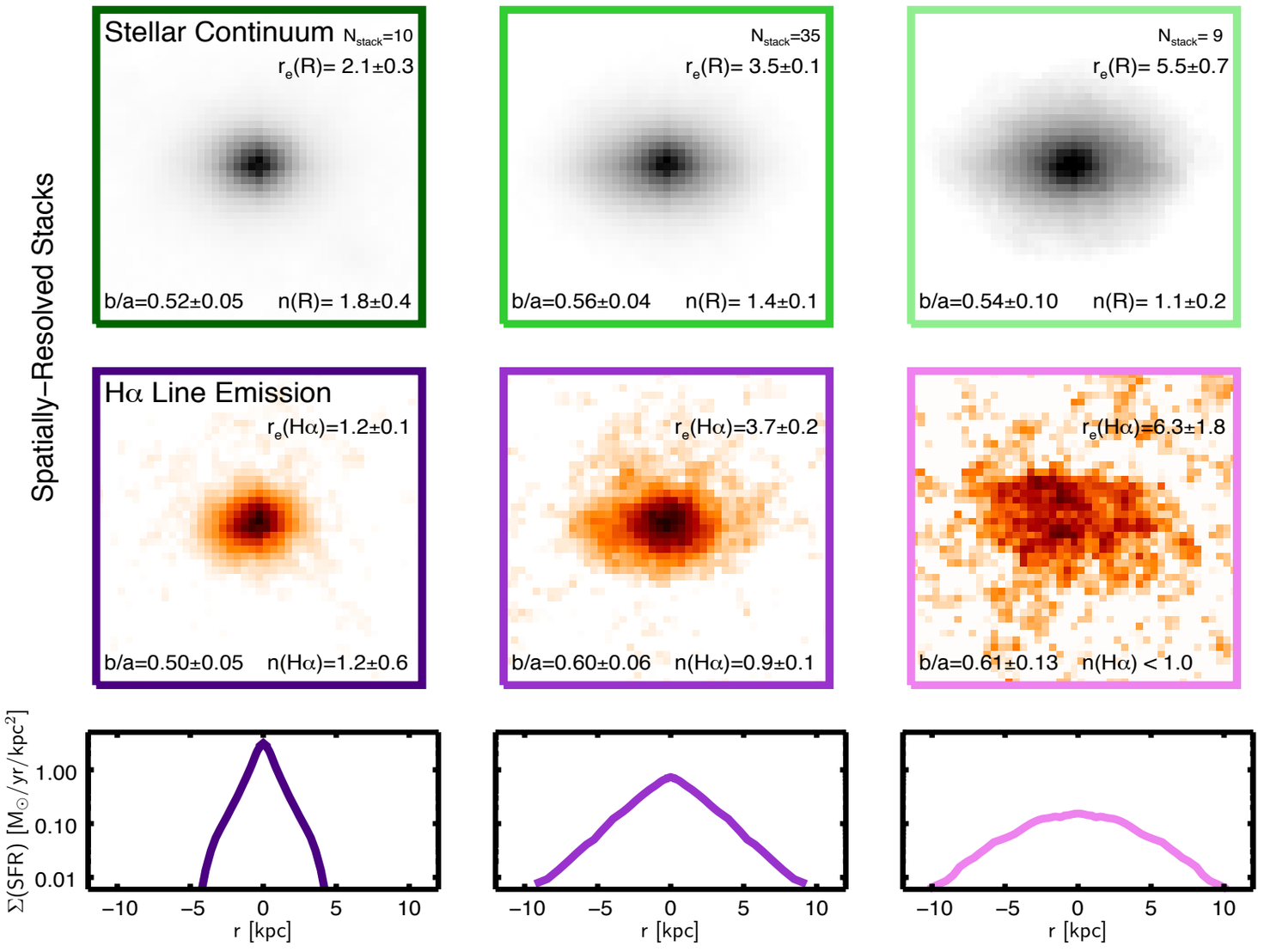
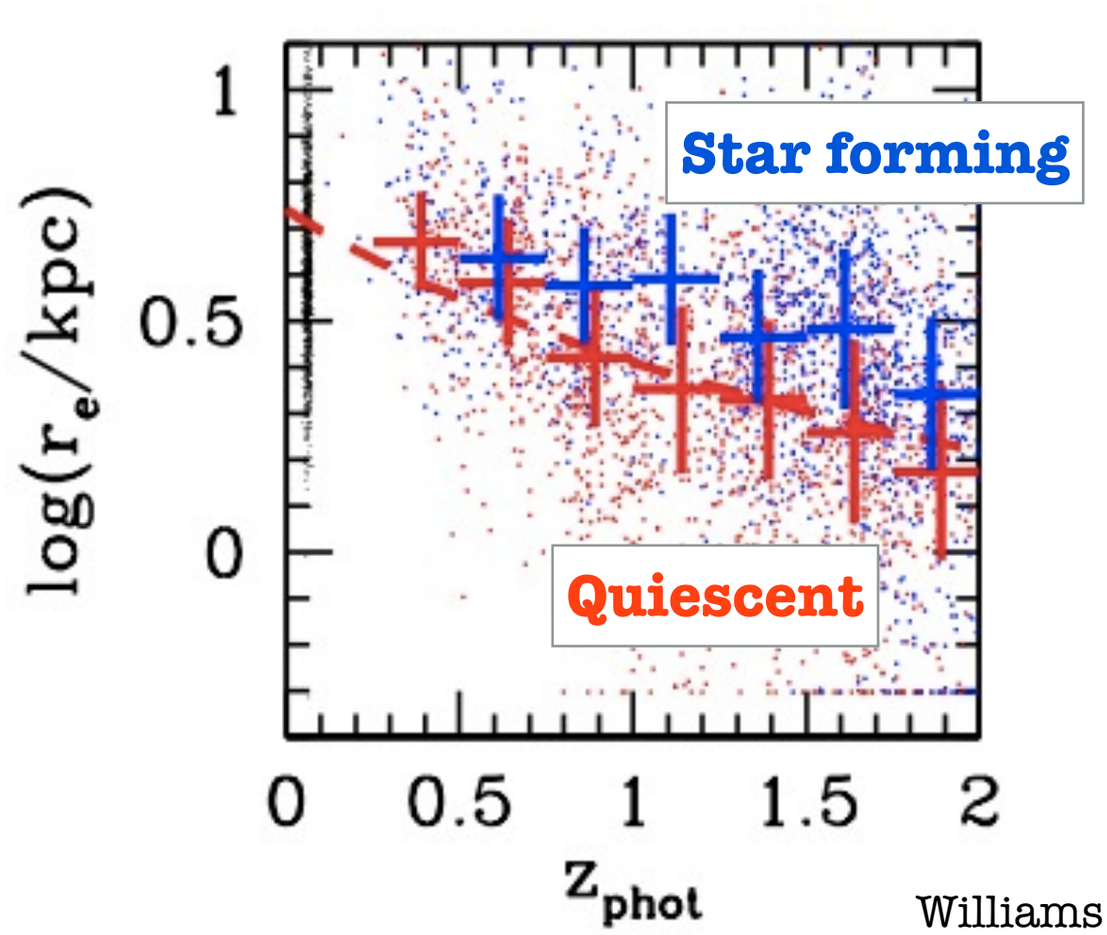


Nelson et al 2012
(see poster!)
also: Wuyts et al 2012

Nature of star forming galaxies

- At high redshift at least some, and apparently most, strong star formation occurred in disks
- Star forming galaxies were smaller, by roughly 1/H(z)



Williams et al 2010

Nature of star forming galaxies

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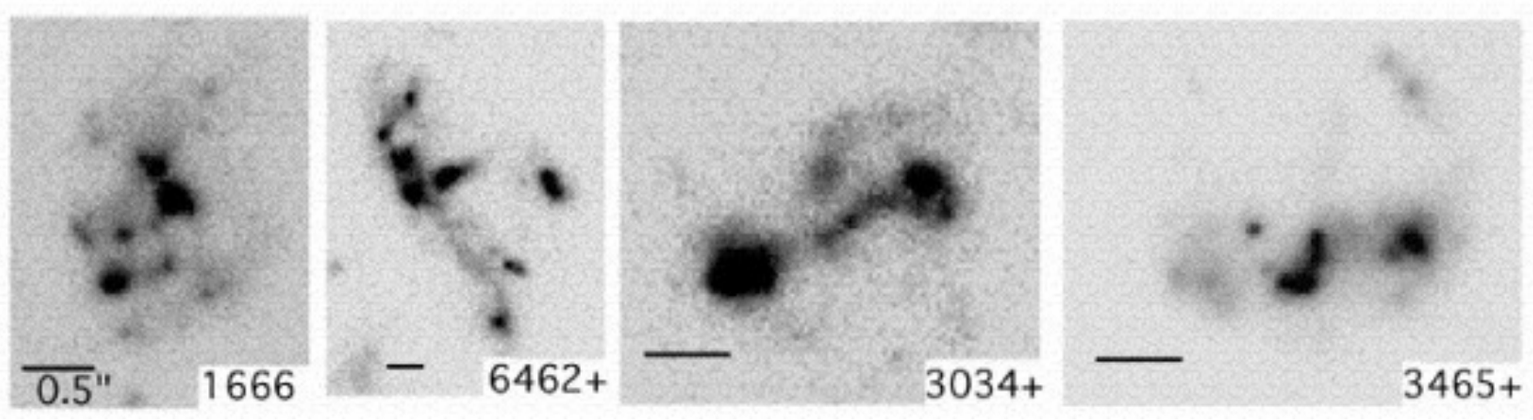
- Star forming galaxies were smaller, by roughly 1/H(z)
- Many galaxies are clumpy, but it is unclear what fraction of star formation takes place in clumps



Elmegreen & Elmegreen 2008, Forster Schreiber et al 2010, Wuyts et al 2012

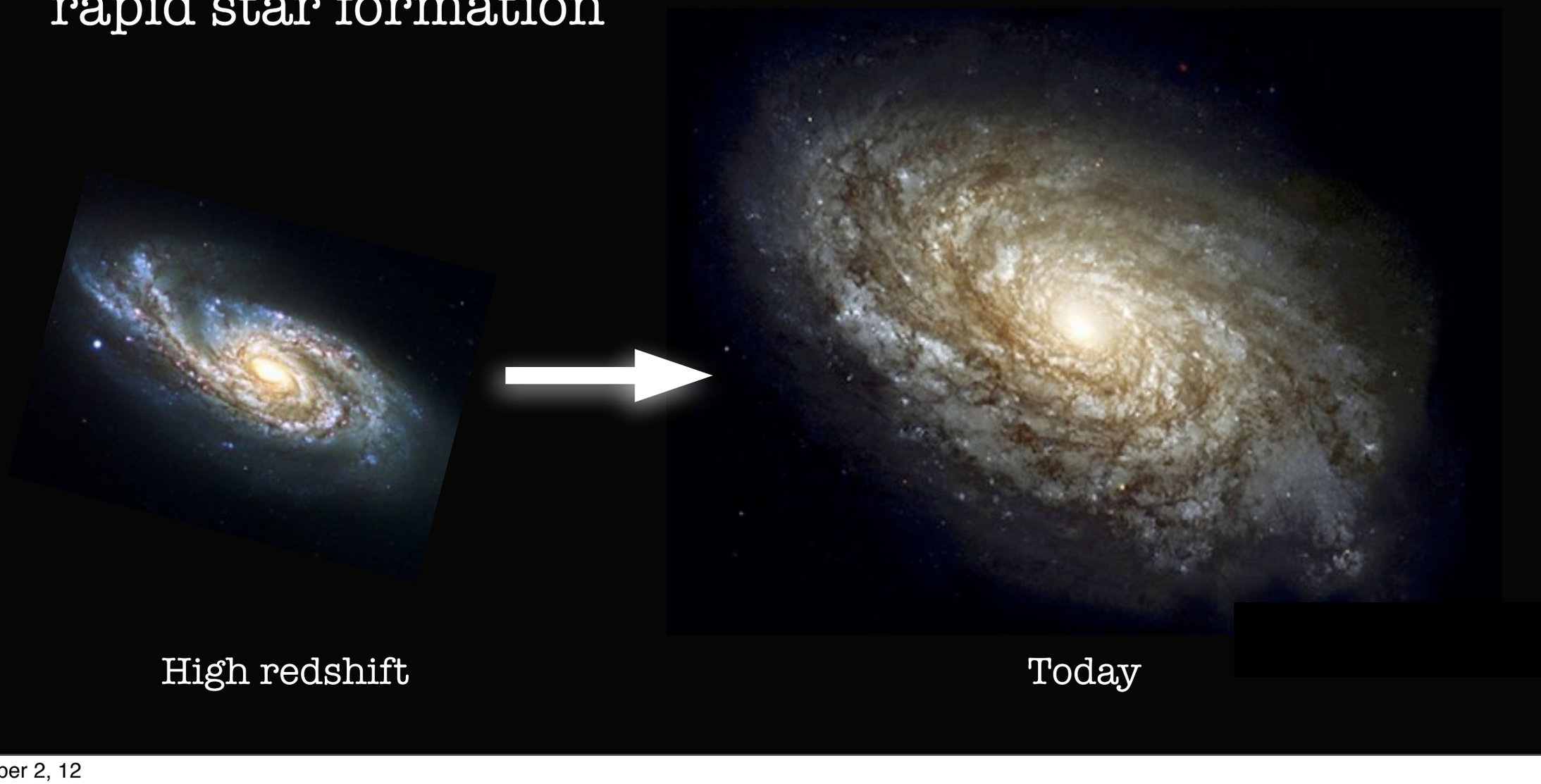
Nature of star forming galaxies

- At high redshift at least some, and apparently most, strong star formation occurred in disks
- Star forming galaxies were smaller, by roughly 1/H(z)
- Many galaxies are clumpy, but it is unclear what fraction of star formation takes place in clumps
- Dynamics often consistent with rotation in rest-optical, and dominated by outflows in rest-UV

(e.g., Franx et al 97, Pettini et al 98-01, Erb et al 03-12, Shapley et al 08, Genzel et al 06-12, Forster Schreiber et al 10-12, Nelson et al 12, and many others)

Cartoon picture

In the past, things were more or less the same - but higher accretion rates onto more compact halos led to higher gas surface densities and therefore more rapid star formation



Problem

- About 50% of stellar mass is in bulges and ellipticals - and these are the oldest stars
- Therefore, majority of stars formed at z>1 should end up in bulges and ellipticals at z=0

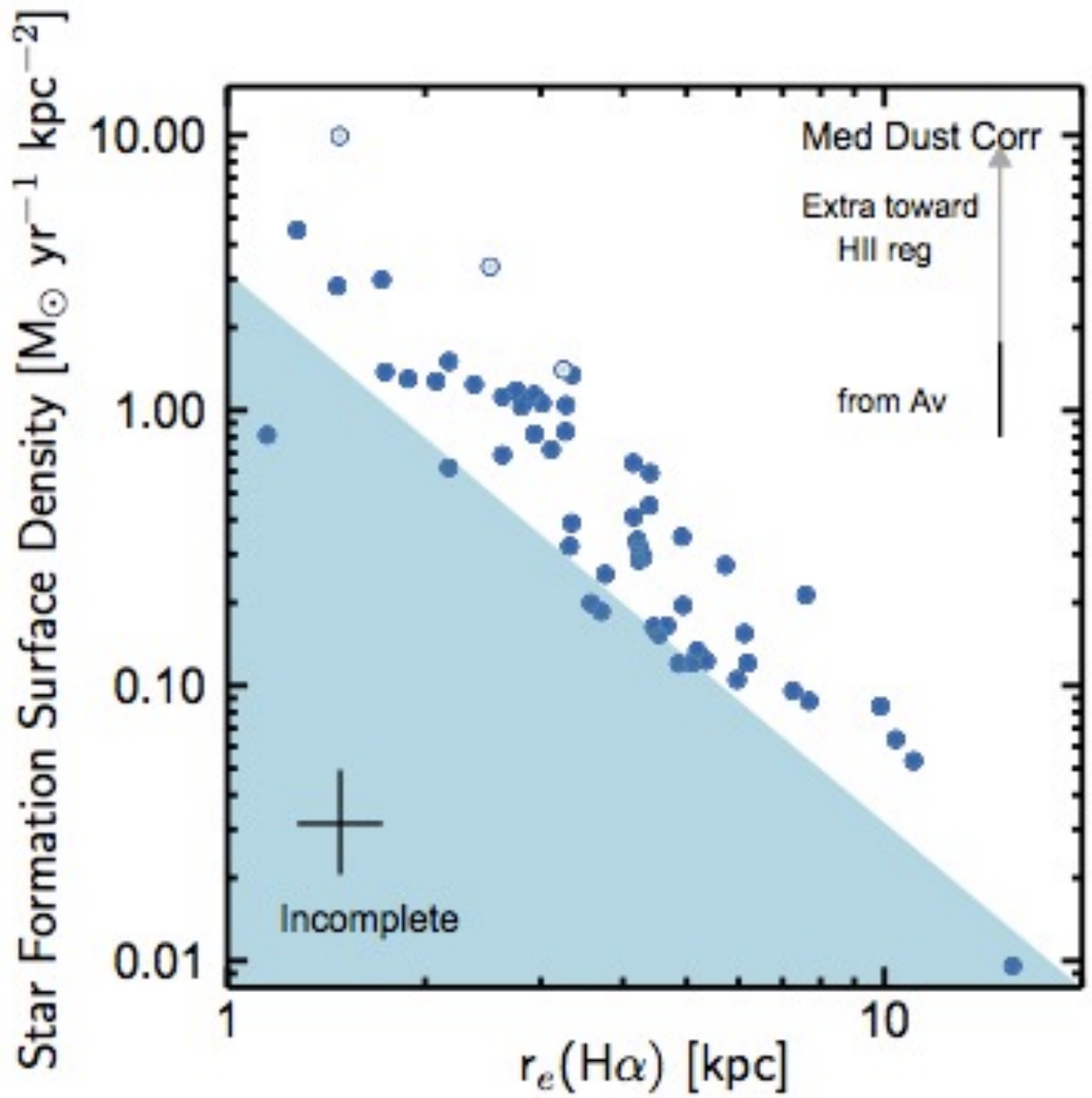
Second mode ?

- Some disks probably undergo mergers, and/or develop bars and bulges

- However, elliptical galaxy formation probably triggered an entirely different mode of star formation (e.g., Naab, Ostriker, etc)

Another look at the z=1-3 Universe

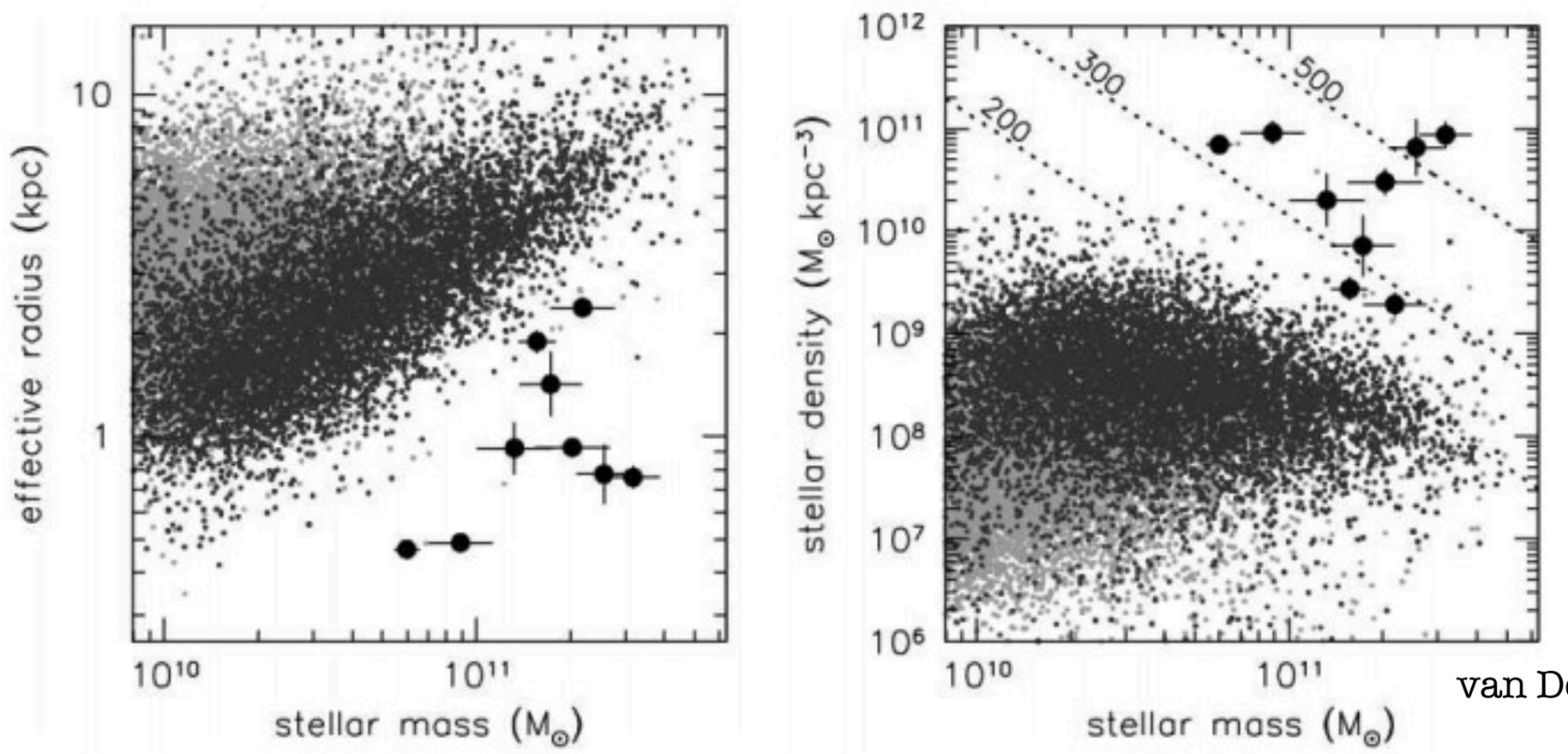
- Sizes of star-forming disks: high degree of diversity among star forming galaxies at z>1



Nelson et al 2012

Another look at the z=1-3 Universe

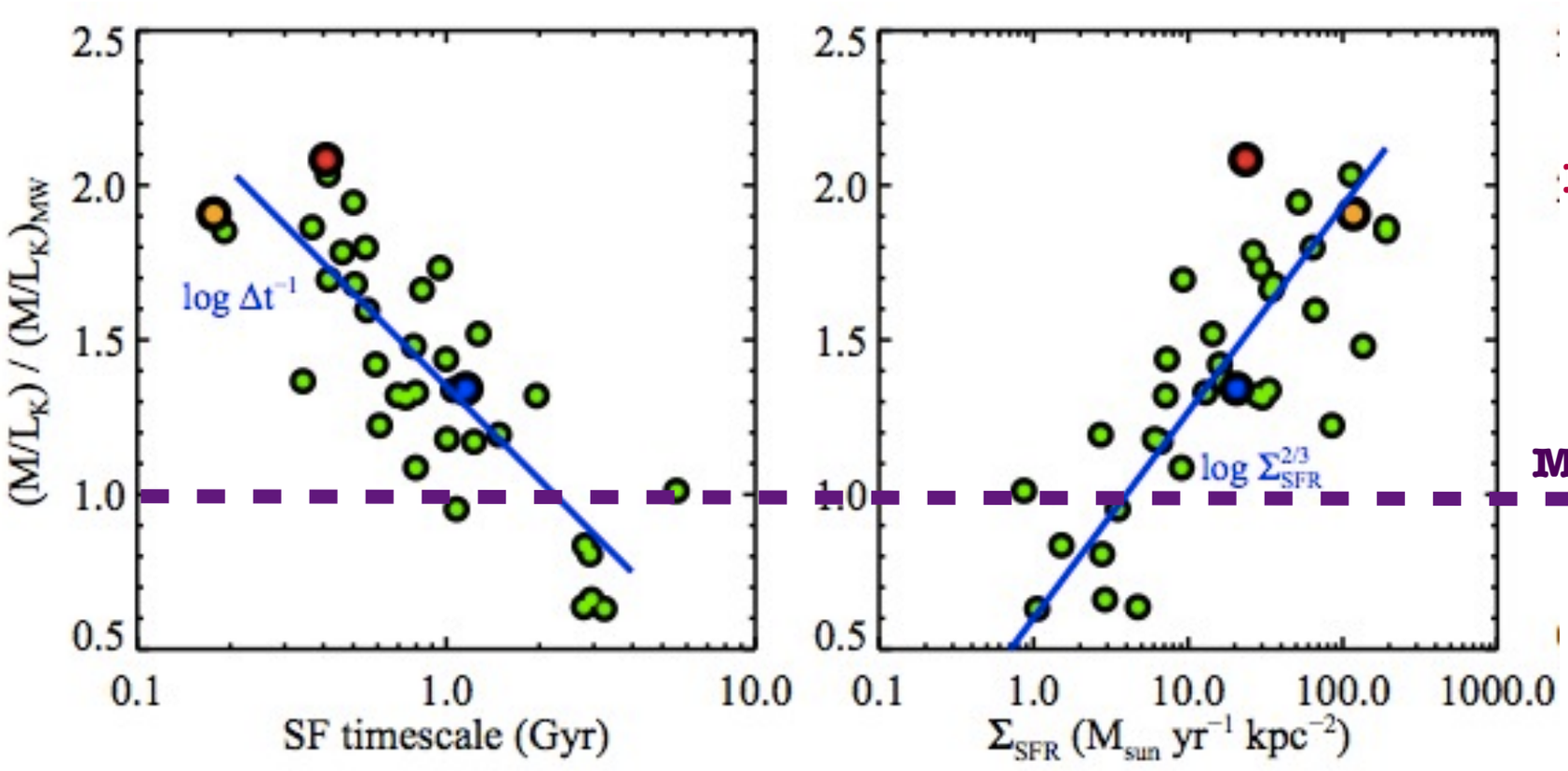
- Sizes of star-forming disks: high degree of diversity among star forming galaxies at z>1
- Population of quiescent galaxies with very low star formation rates and very small sizes



van Dokkum et al 08

Compact, massive galaxies

- Probably the cores of today's elliptical galaxies (based on number density arguments)
- Must have had extremely high gas densities, turbulence, and perhaps bottom-heavy IMF



Conroy & van Dokkum 2012; also Larson 1998, 2005; Hopkins et al 2012, Krumholtz et al 2012, etc

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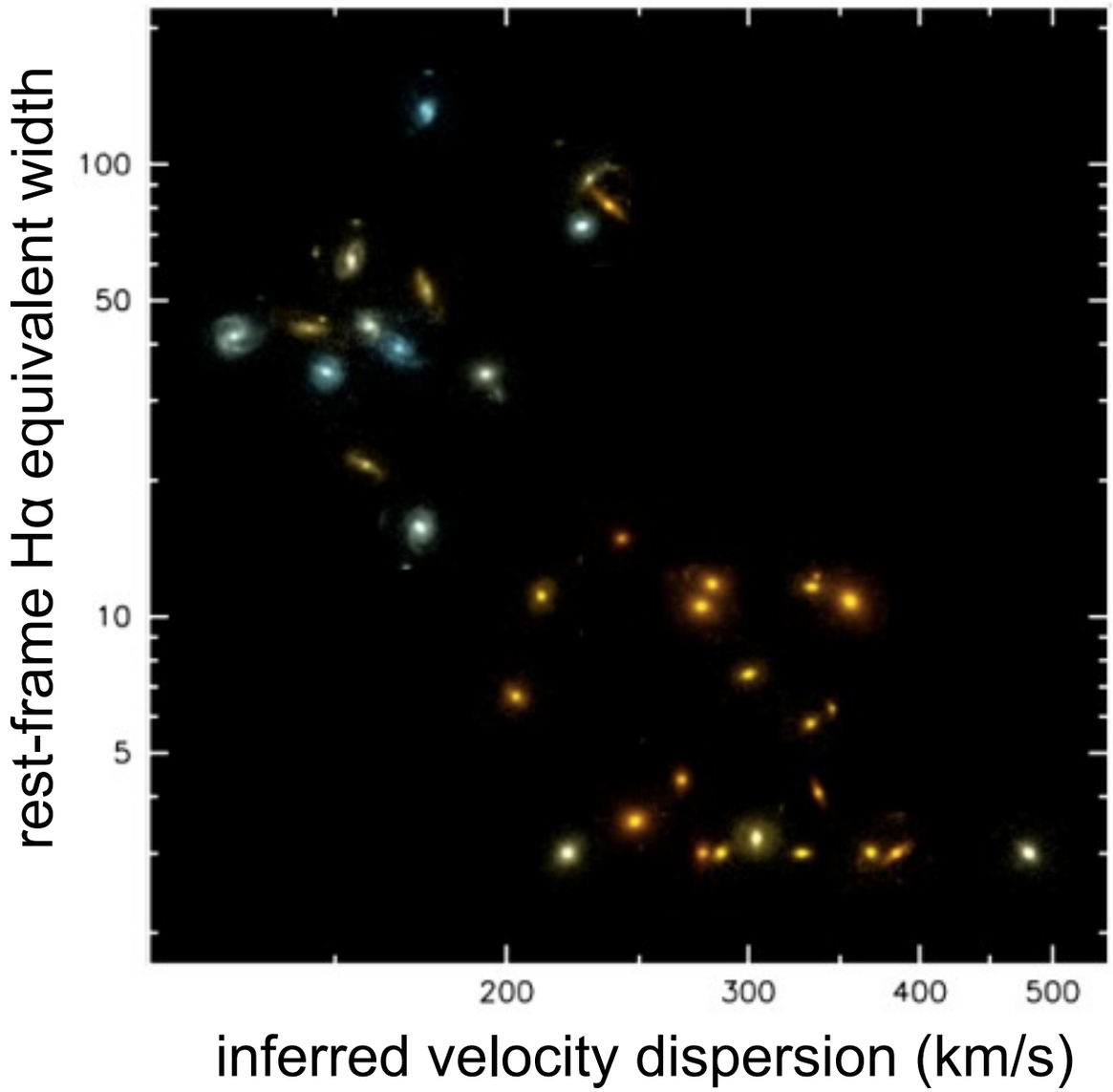
Another look at the z=1-3 Universe

- Period of maximal diversity, that we have only just begun to explore



3D-HST survey
van Dokkum et al 11

Another look at the z=1-3 Universe

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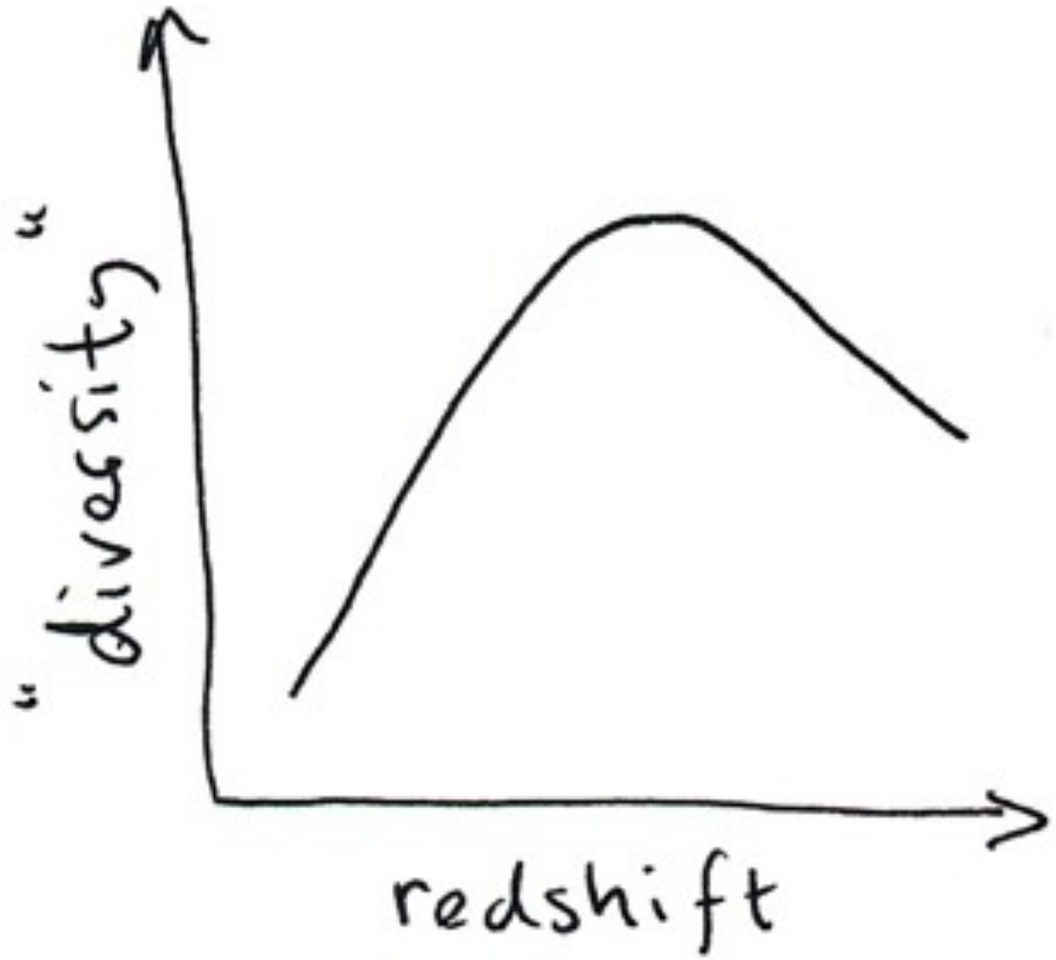
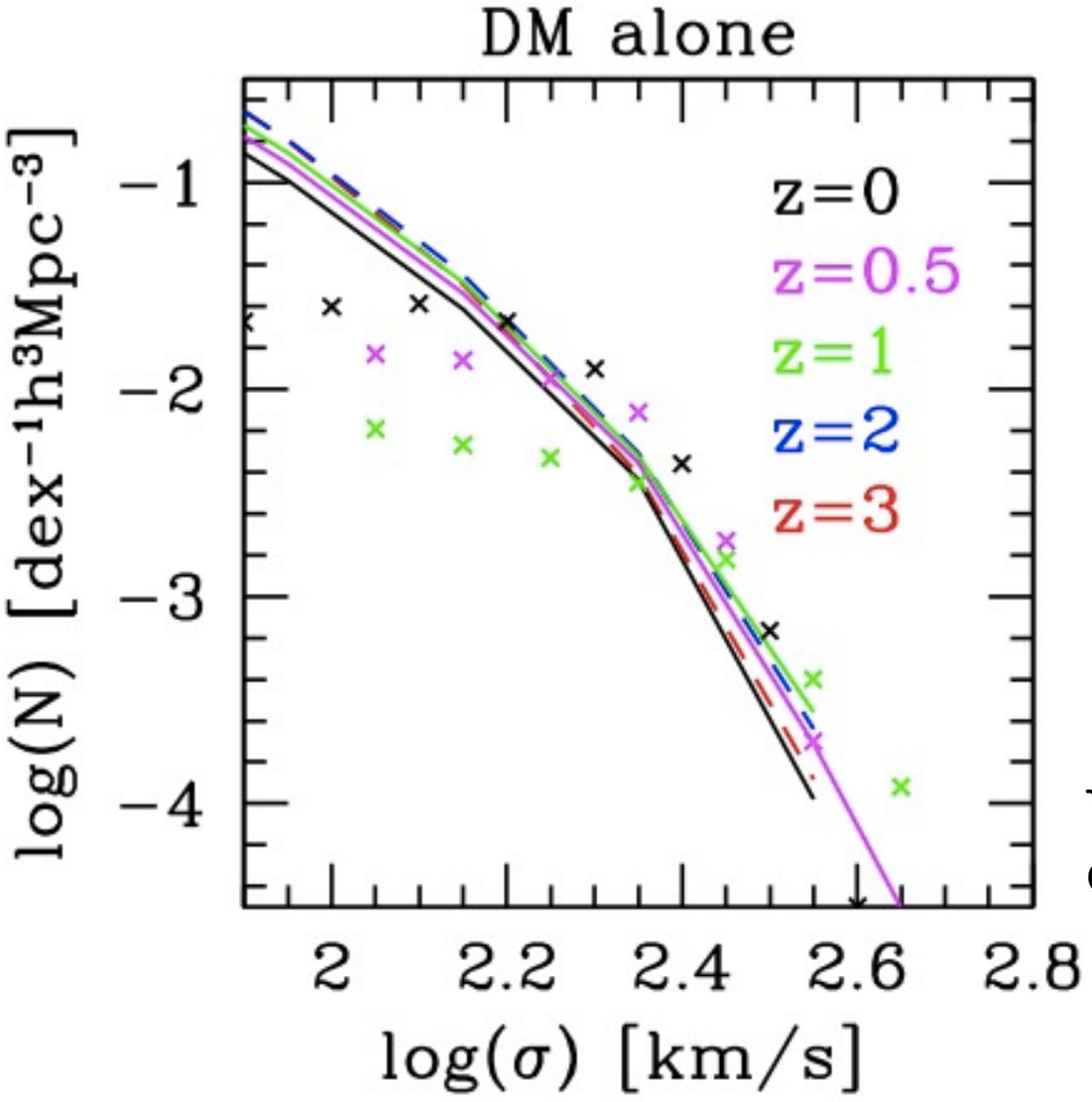


Near future

- ALMA:
  - Calibrate relation between SFR and gas density
  - Find obscured star-forming progenitors of compact galaxies
  - Map “true” star formation distribution
- Mapping of outflows and (possibly) cold streams
(Rudie et al, etc)
- Kinematics of high redshift galaxies: circular velocities may be remarkably stable

- Velocity function of dark matter within 20 kpc



Weinmann et al, in prep;
data: Bezanson et al 2011, 2012

A MODEL FOR THE FORMATION OF A SPHERICAL GALAXY

Richard B. Larson

(Communicated by P. Demarque)

(Received 1969 March 24)

SUMMARY

Numerical calculations have been made for a model representing the collapse of an initially gaseous proto-galaxy and the concurrent transformation of gas into stars. The assumed turbulent motions of the gas are represented by a simple model consisting of discrete colliding clouds, and the star formation rate is assumed to be given as a simple function of the density and turbulent velocity of the gas. The gas clouds and the stars are then treated separately by means of fluid-dynamical equations derived from the Boltzmann equation. It is found that, by assuming reasonable values for the various parameters of the model, it is possible in this way to reproduce reasonably well the observed properties of spherical and nearly spherical galaxies.