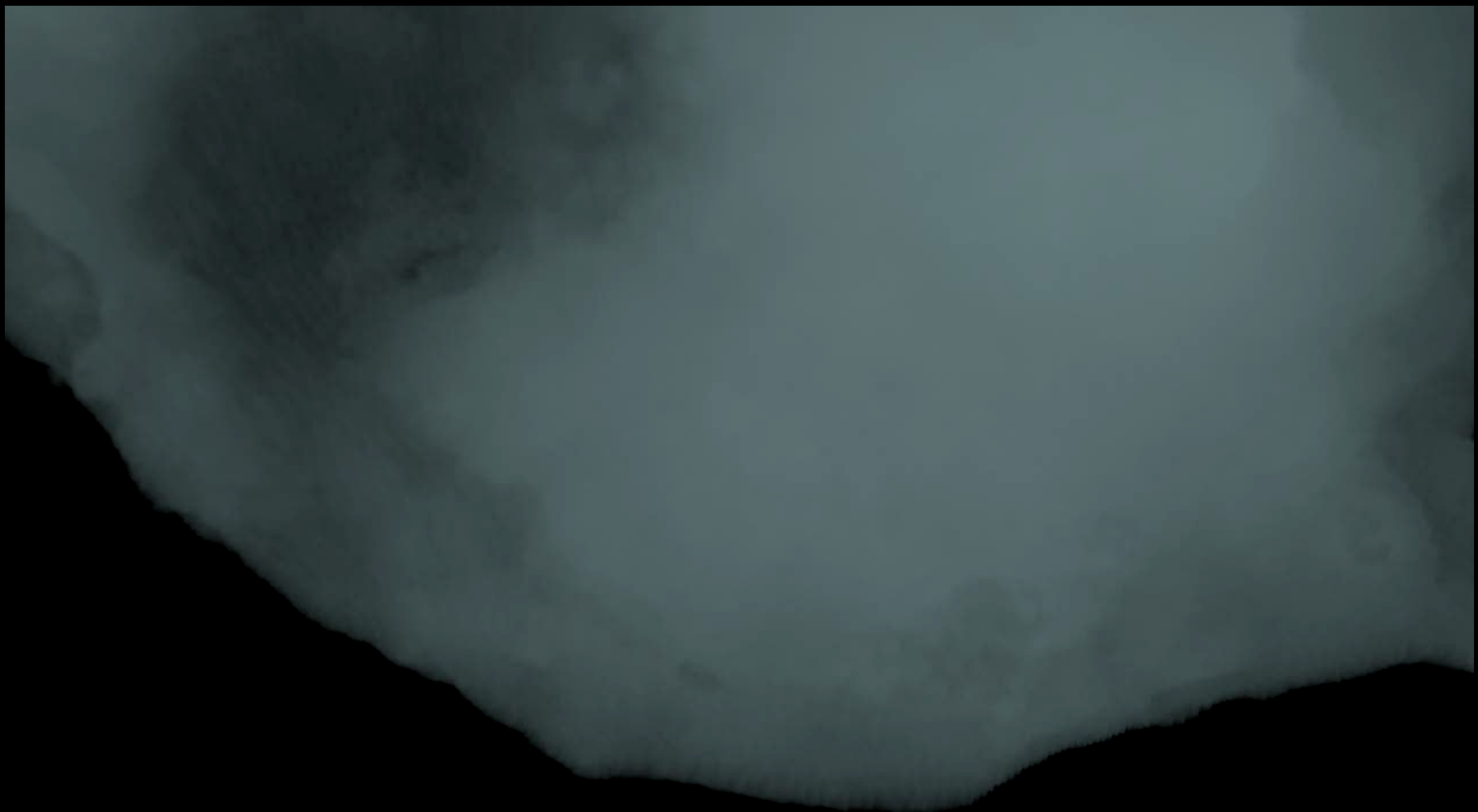
The Epoch of Disk Settling: z~1 to Today



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Simulation by Fabio Governato , V=220 km/s, 50 Mpc box, 170 pc resolution, H2 + Z line cooling

What do these simulations tell us about galaxy formation?

- Much of the mass and angular momentum of galaxies may come from cold flows
- There is more merging/accretion at early times

At a redshift of about 1…

Blue galaxies are for the most part in place,

- M_B brighter by only ~1 mag compared to today (e.g., Bell+04, Willmer+06, Faber+07)
- Number density doesn't change (ditto)
- Stellar mass unchanging *to within uncertainties* (e.g., Bundy+06,Borch+06, Pozzetti+10)
- Sizes are only marginally smaller (factor of 1.4; Dutton+11)

but there are hints that they are different beasts than blue galaxies today.

- Higher star-formation rates by x10 (e.g., Noeske+07)
- More disturbed morphologies (e.g., Abraham & van den Berg+01, but see Oesch+10 for higher mass)
- Higher molecular gas fractions (Tacconi+10, Daddi+10)

What's going on? Let's look to kinematics.

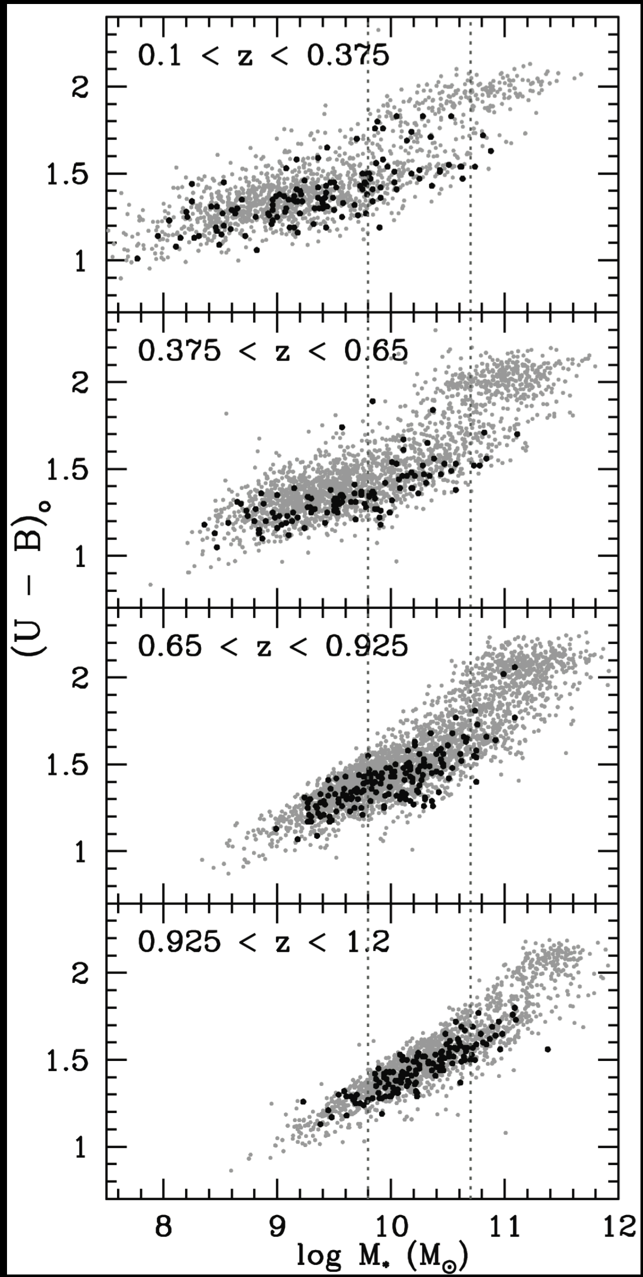
Sample selection is key!

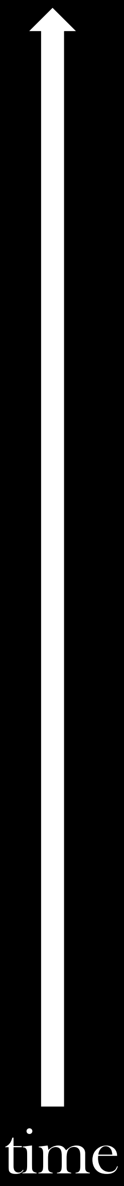
- If we select high-z galaxies to be like those today, we will minimize evolution.

Our final sample is selected essentially on magnitude (R_{AB} < 24.1) and emission line strength.

DEEP2 Kinematics Sample: Distribution in Color-M_*

- ~10K galaxies in DEEP2 field 1 (grey)
- 544-galaxy sample discussed in this talk (black) follows "blue cloud"



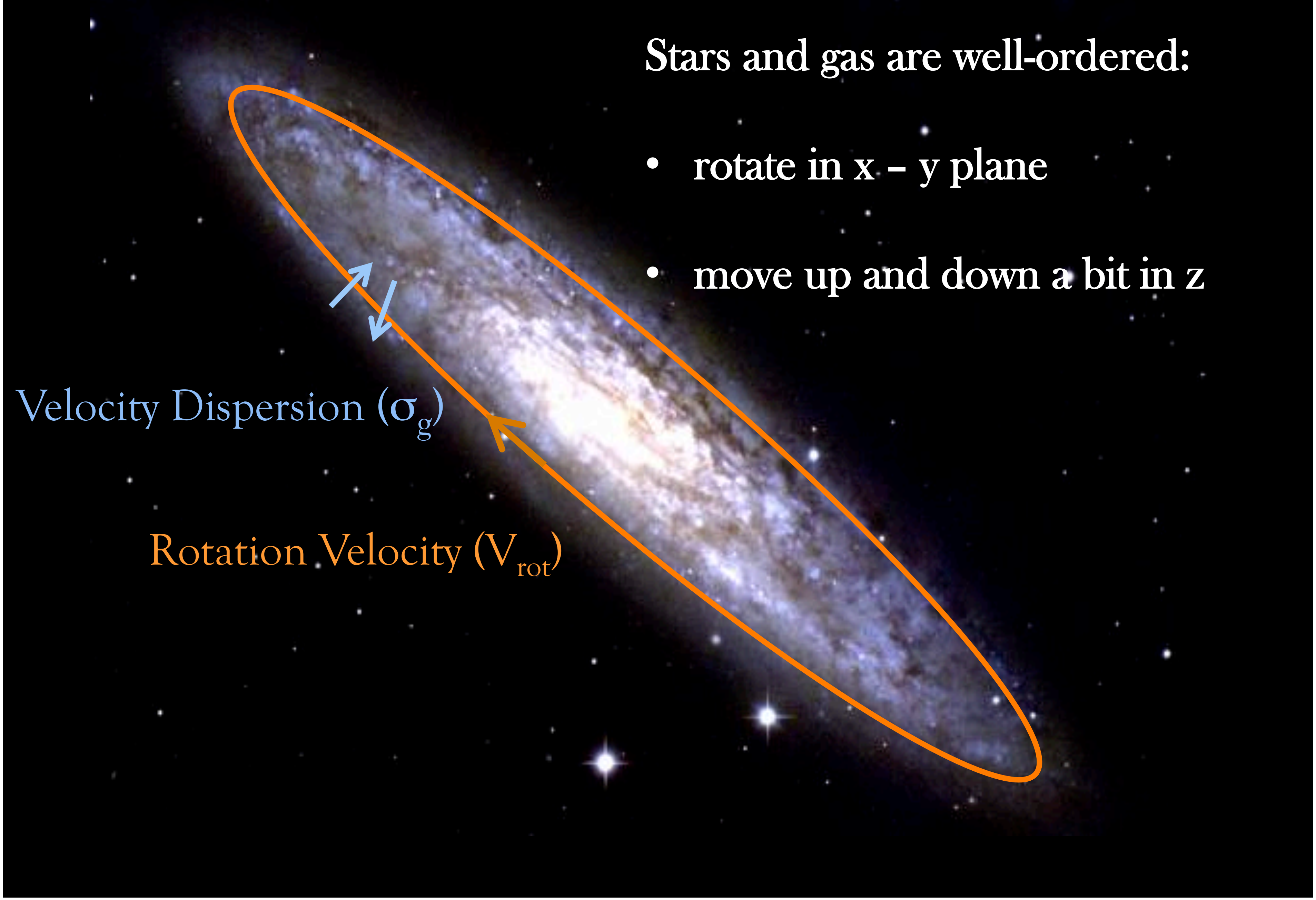


SAK+12b

Most Blue Galaxies Today Play Nice

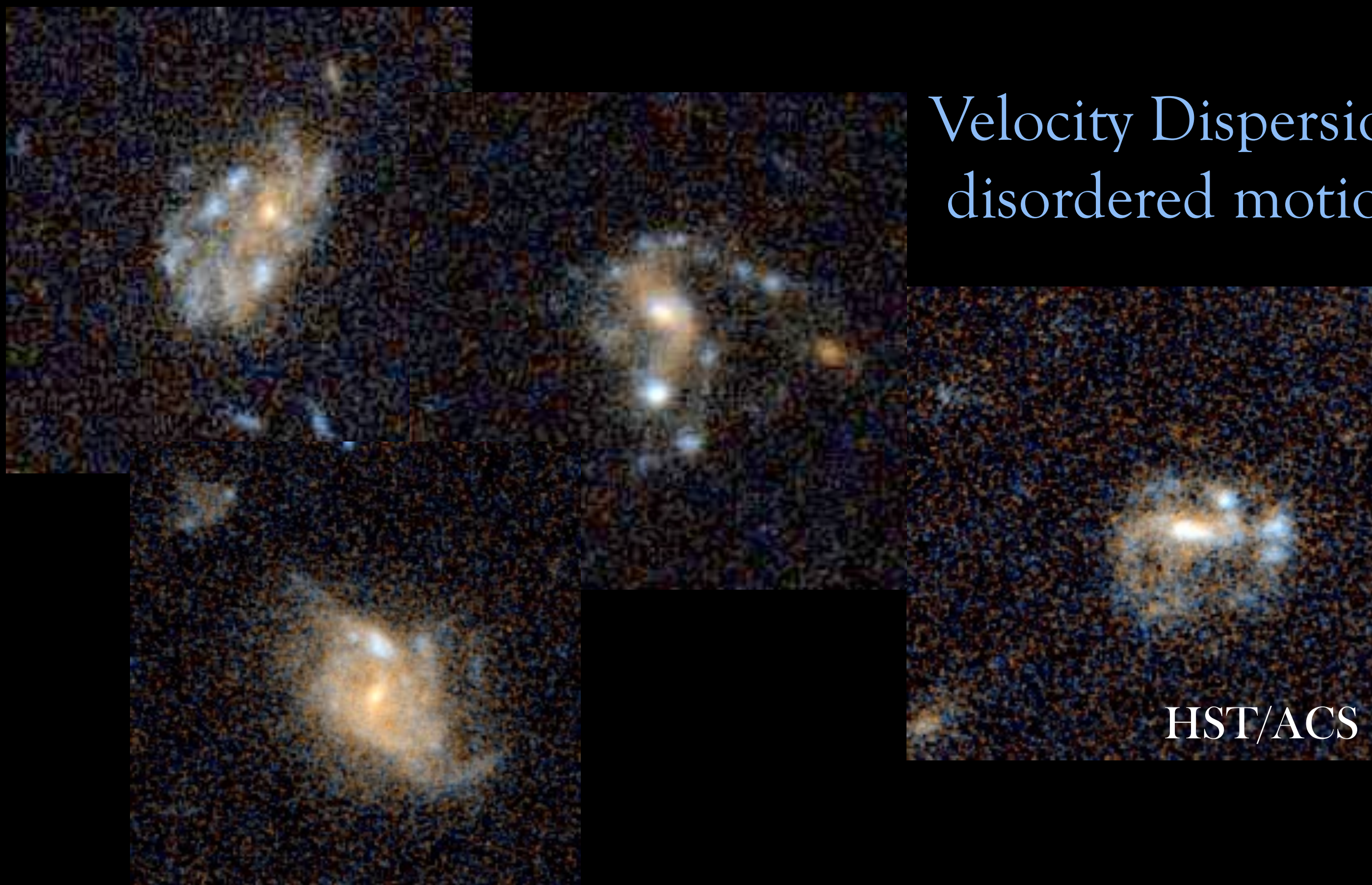
Stars and gas are well-ordered:

- rotate in x – y plane
- move up and down a bit in z



Most Blue Galaxies at $z \gtrsim 1$ Play Rough

They **rotate** and show disordered motions

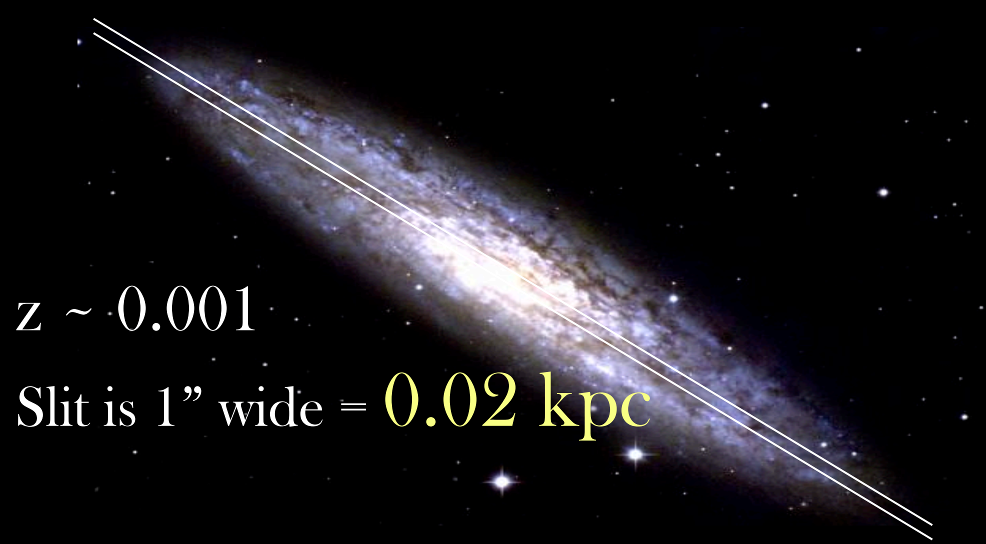


Velocity Dispersion (σ_g) quantifies disordered motions…

Rotation Velocity (V_{rot})

(…like our Milky Way once was)

σ_g is Different at High Redshift

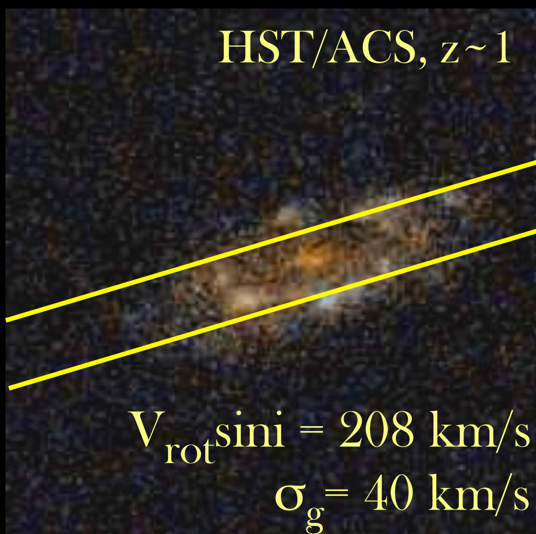


Galaxy spectra are observed with thin slits… but galaxies are smaller in the past

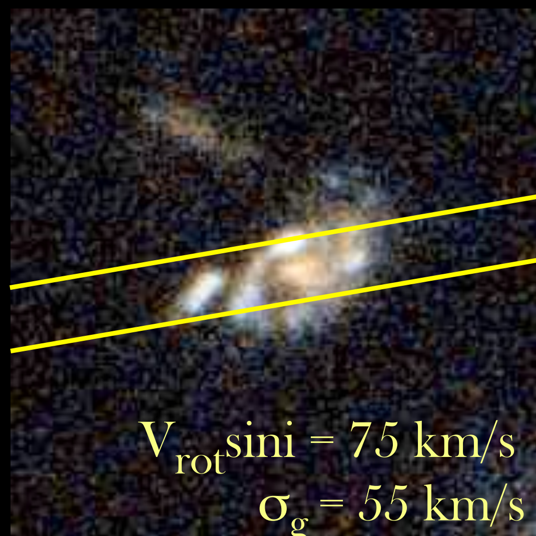
At High-z, σ_g Quantifies the Amount of Disordered Motions

3 Example Galaxies:

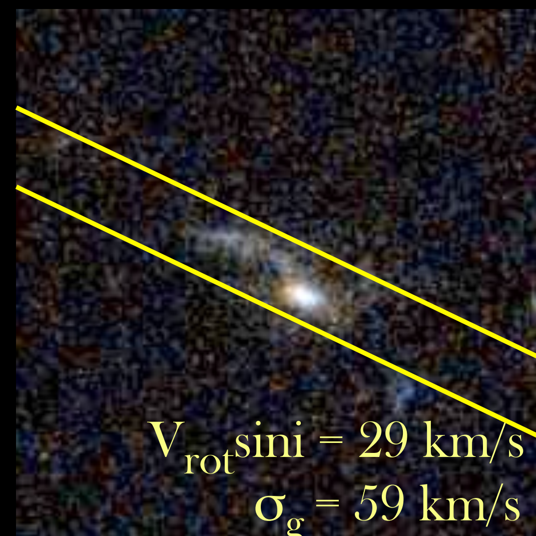
V_{rot} - dominated



Mixed



σ_g - dominated

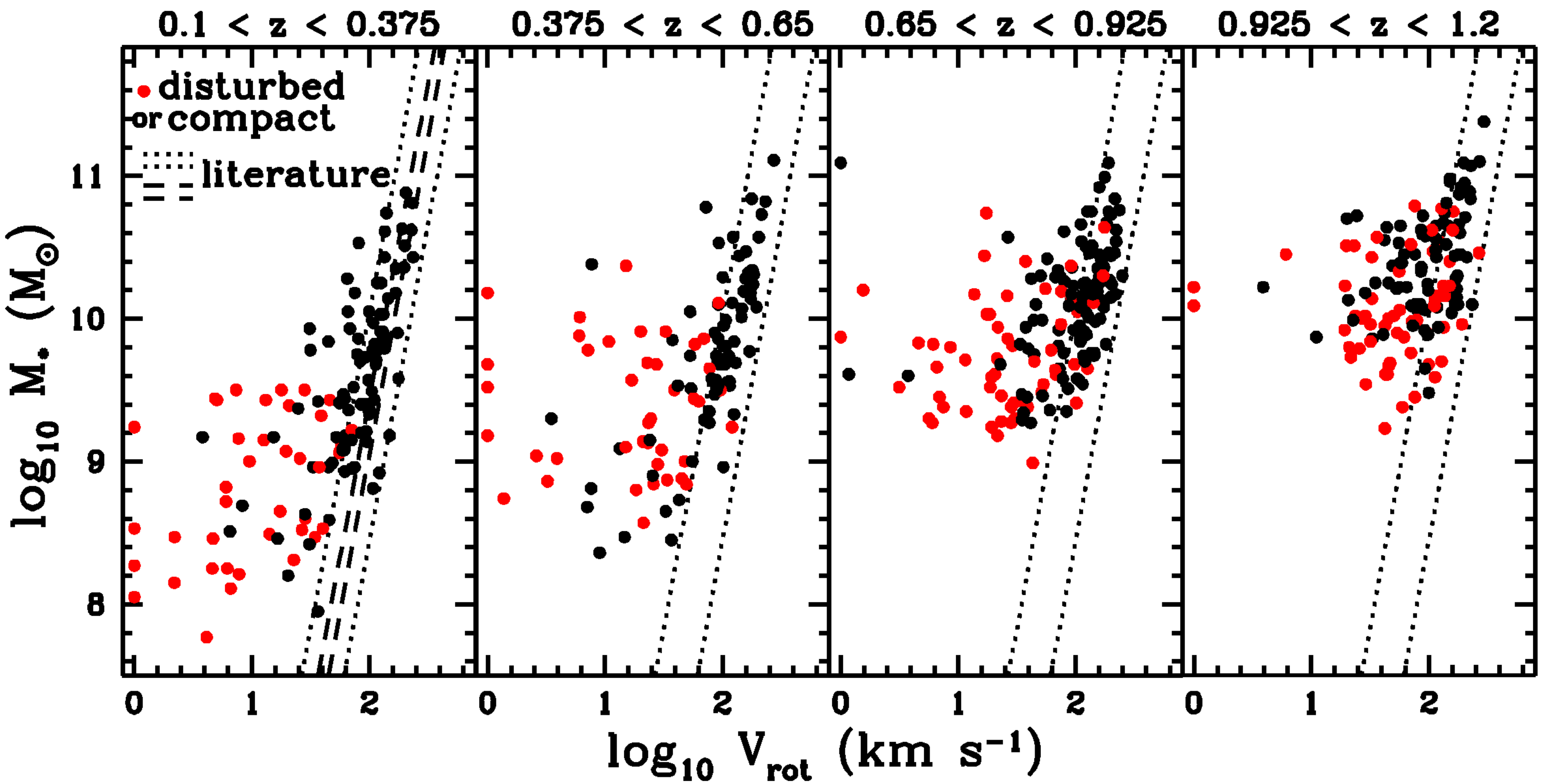


Kinematics are measured from spectra and the effects of seeing are modeled

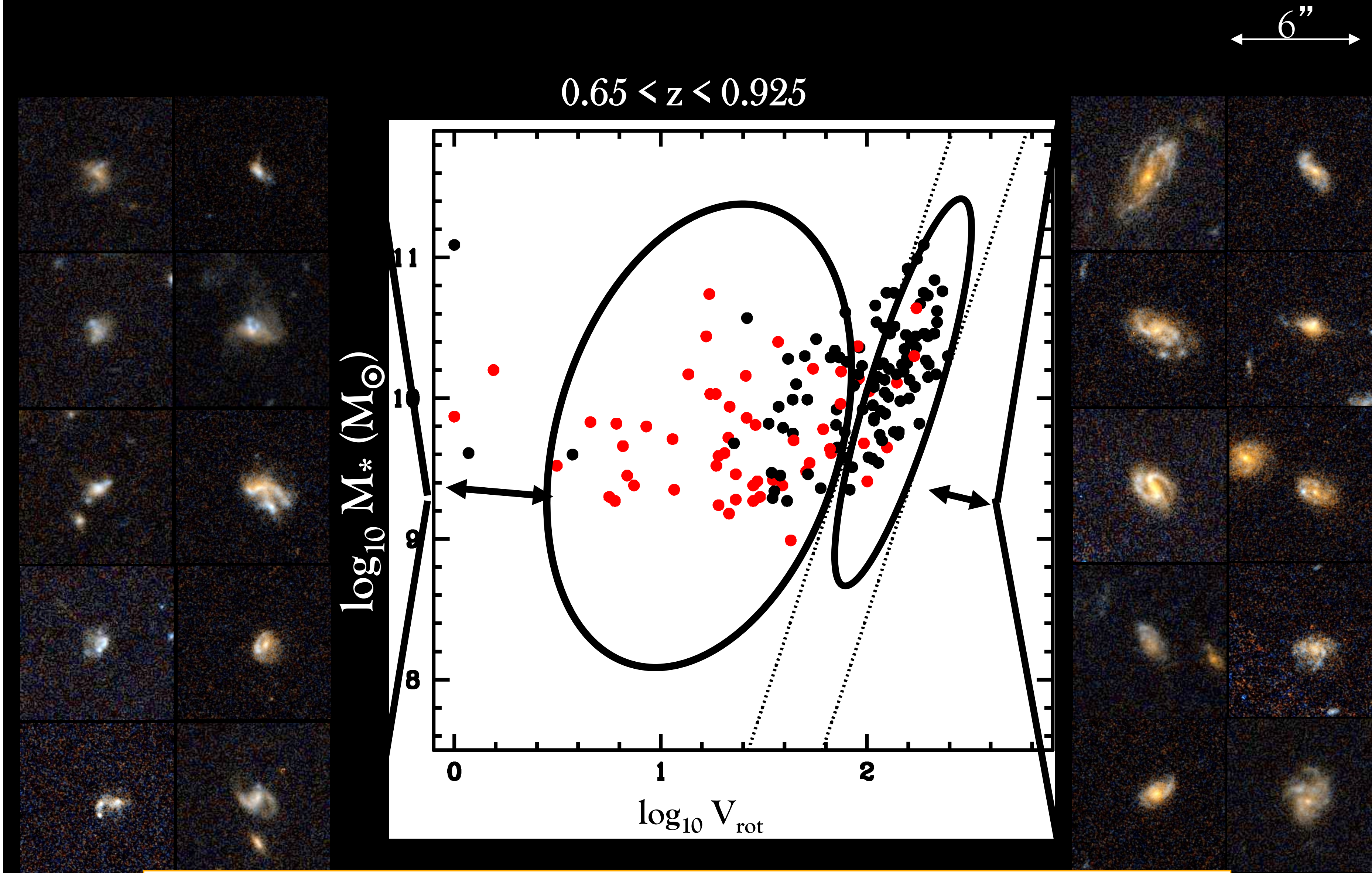
Weiner+ 06a,b, Kassin+07, Covington+10

Stellar Mass Tully-Fisher Relation Since z=1.2

Redshift -->



Generally Only Well-Ordered Galaxies Lie on Ridgeline

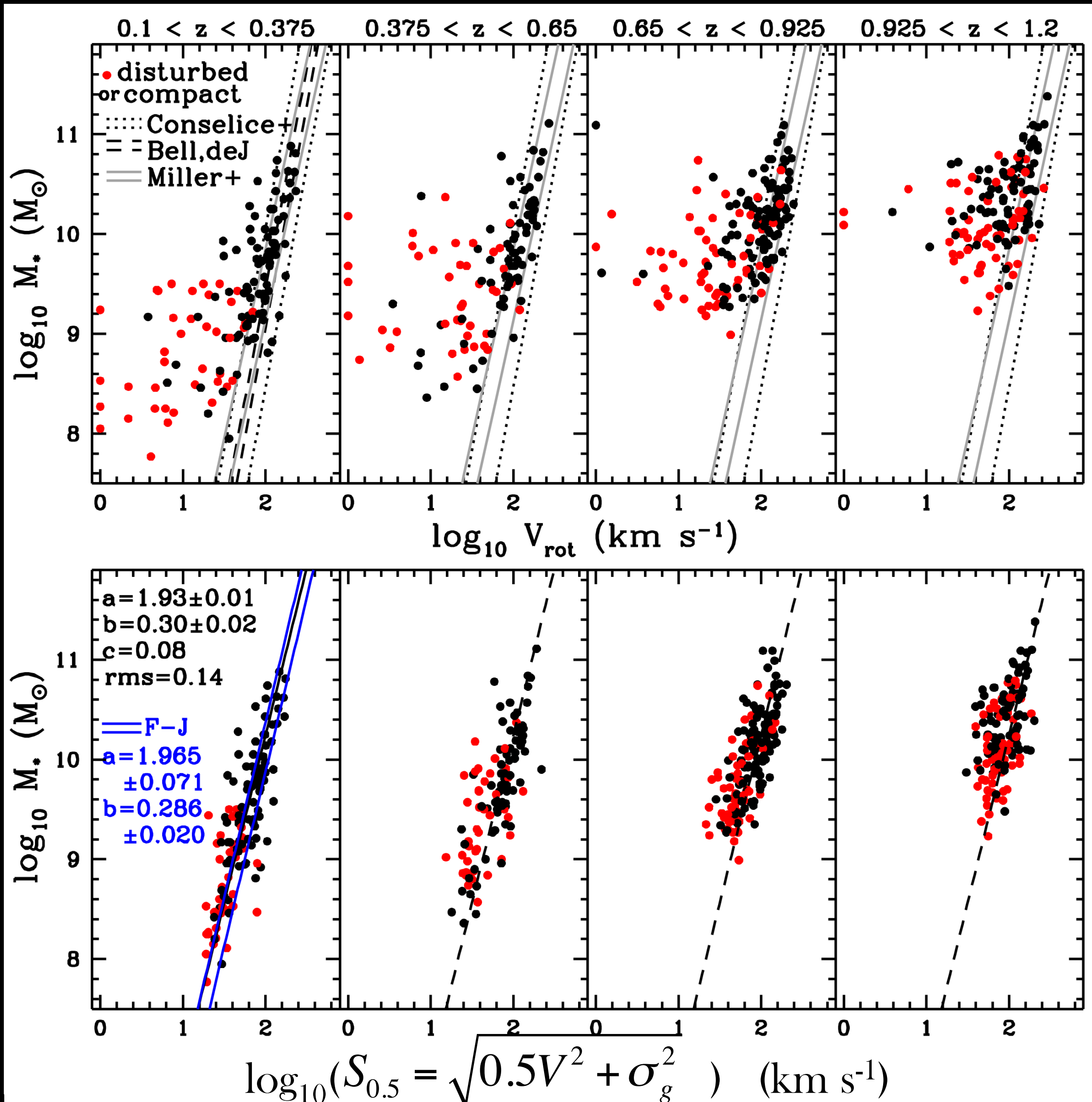


• = disturbed or compact morphology • = normal morphology

New Kinematic Quantity to Trace Galaxy Potential Wells

$$S_{0.5}^{2} \equiv 0.5V_{rot}^{2} + \sigma_{g}^{2}$$

Stellar Mass Tully-Fisher Relation



Faber-Jackson from Gallazzi+06

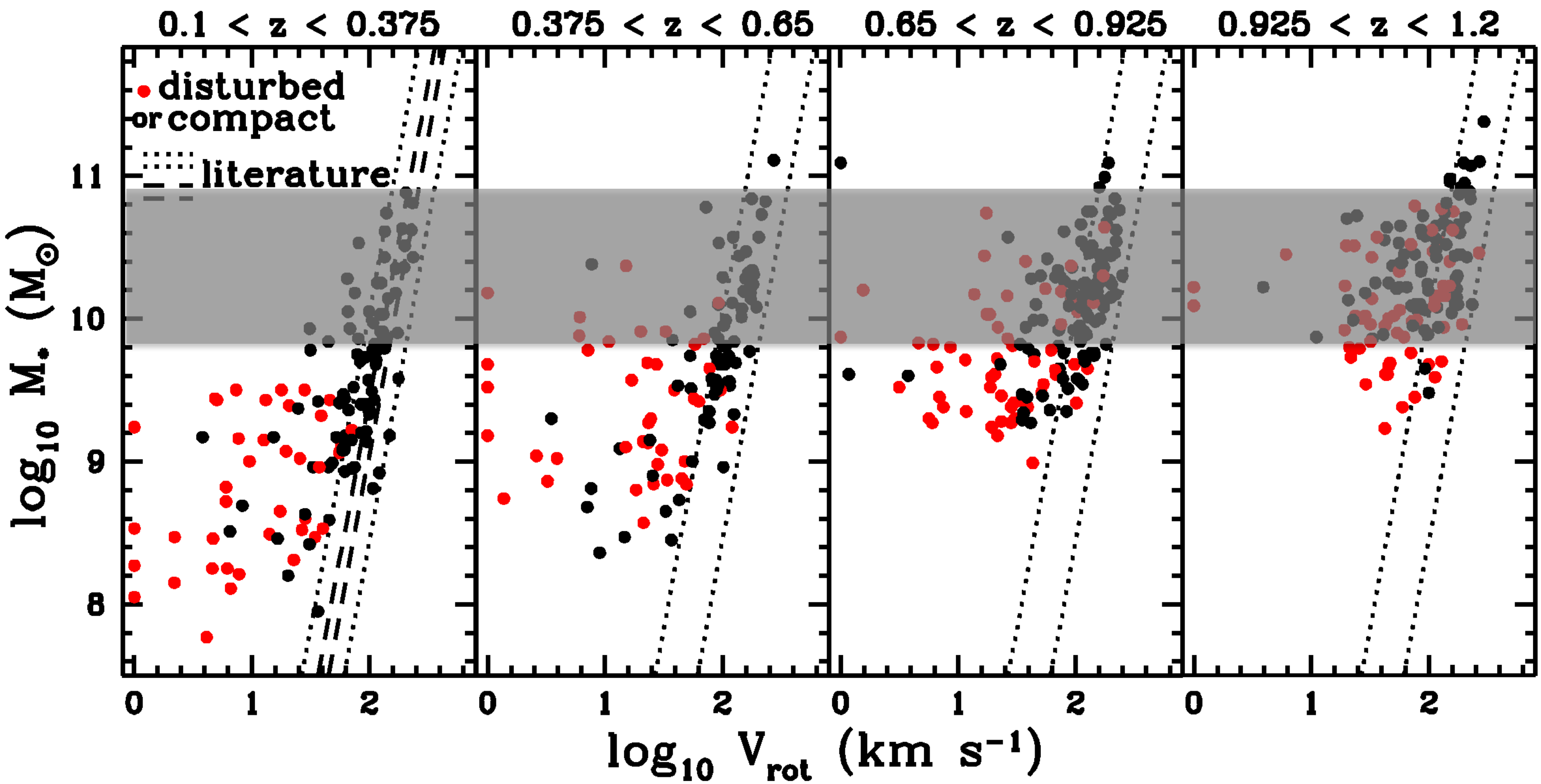
$\log S_{0.5} = a + b \log M_*$

c=intrinsic scatter

SAK+07

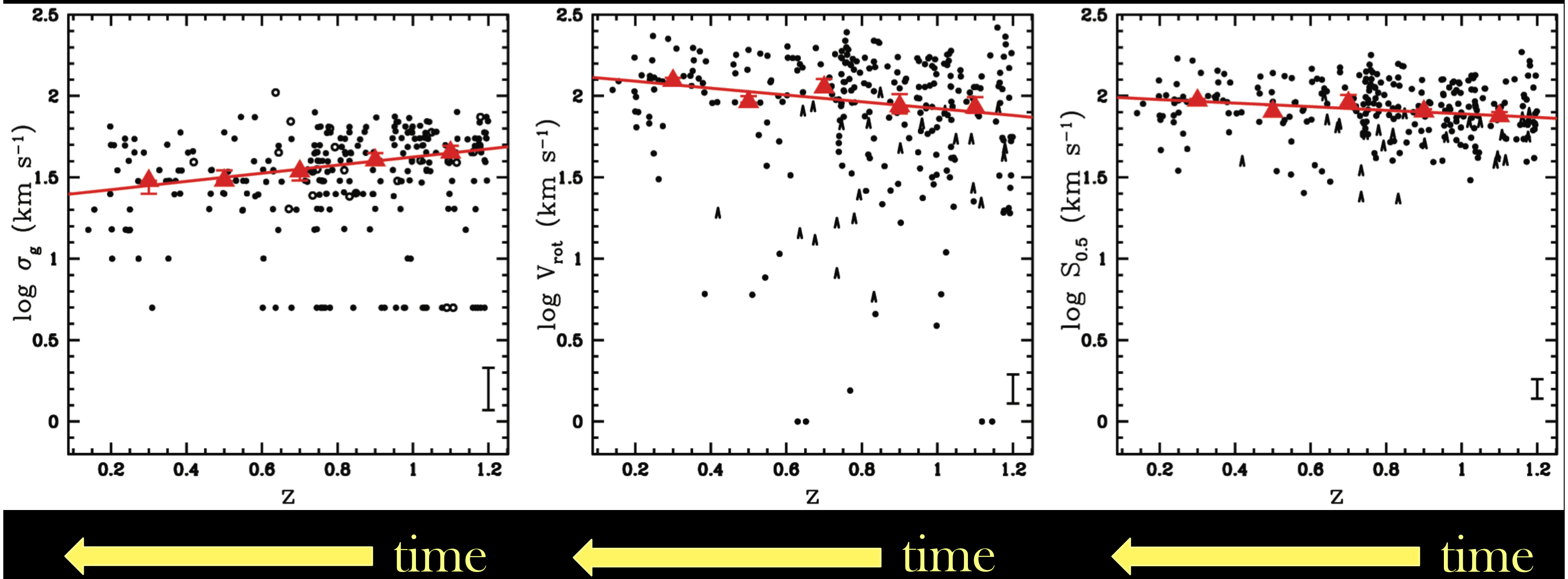
Creating a Mass-Limited Sample

$9.8 < \log M_* (M_\odot) < 10.7$



Kinematic Evolution of the Mass Limited Sample

(9.8 < log M_* ($M_\odot$) < 10.7)



Decrease in σ_g (5.0σ significance)
Increase in V_{rot}(4.2σ) and $S_{0.5}$ (3.6σ) with time.

Blue galaxies become more ordered and increase in potential well depth over the last 8 billion years.

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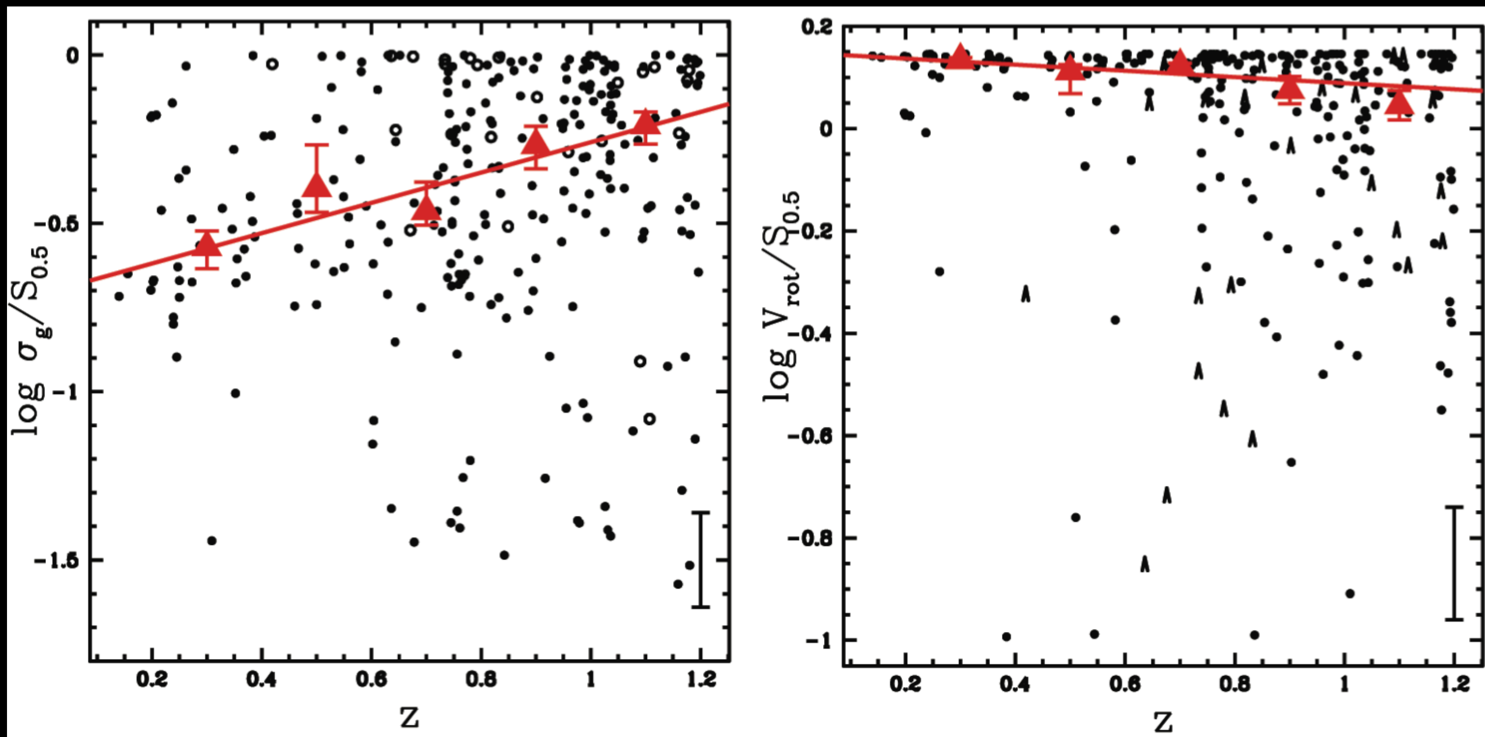
Kinematic Evolution of the Mass Limited Sample

(9.8 < log M_* ($M_\odot$) < 10.7)



time　　　　time

Decrease in $\sigma_g/S_{0.5}$(5.0σ) and Increase in $V_{rot}/S_{0.5}$ (3.0σ) with time

Blue galaxies become more ordered and increase in potential well depth over the last 8 billion years.

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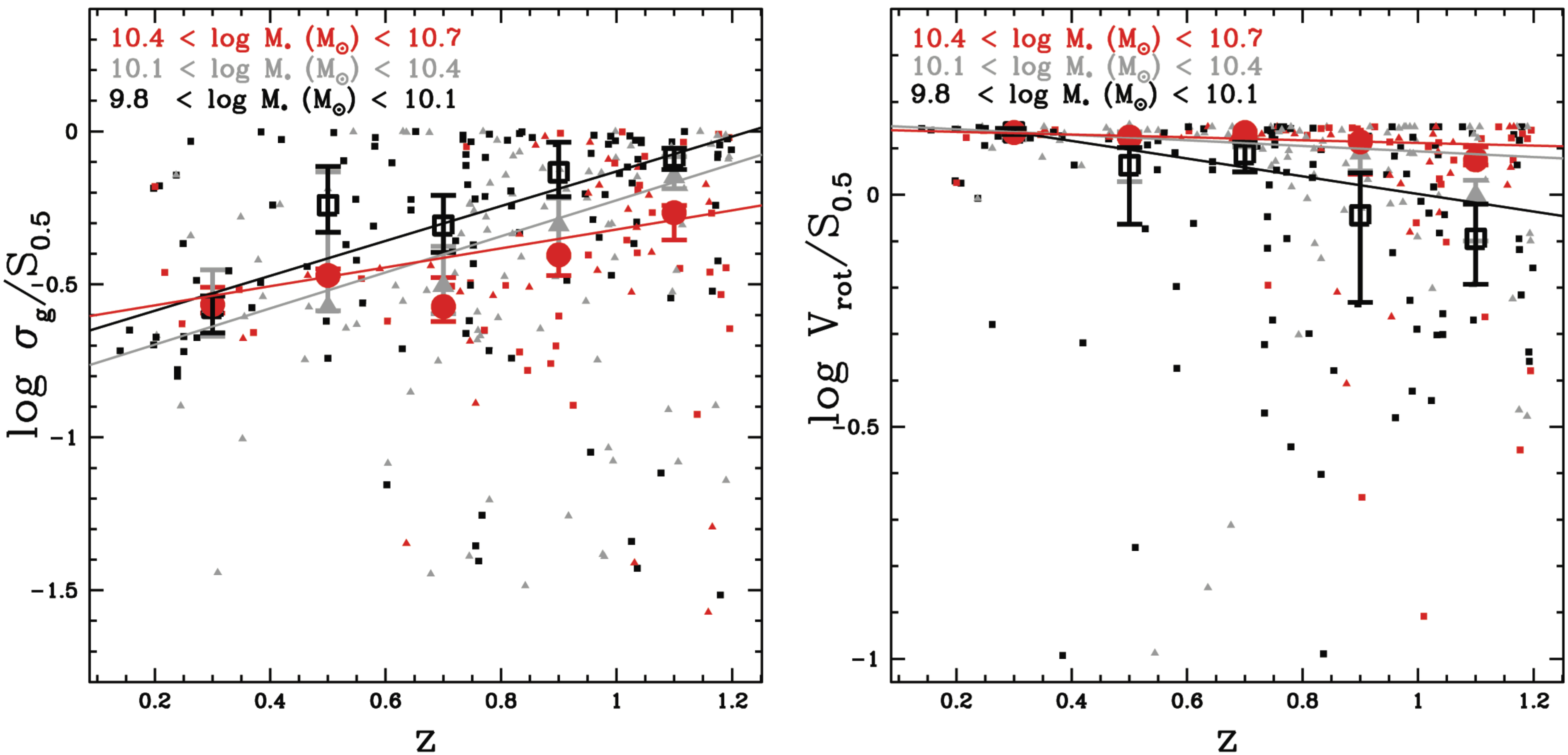
"Kinematic Downsizing"

(M_* limited sample: $9.8 < \log M_* (M_\odot) < 10.7$)



Higher mass galaxies are the most evolved at all z (higher V_{rot}, lower σ_g).
Lower mass galaxies are the least evolved at all z (lower V_{rot}, higher σ_g).

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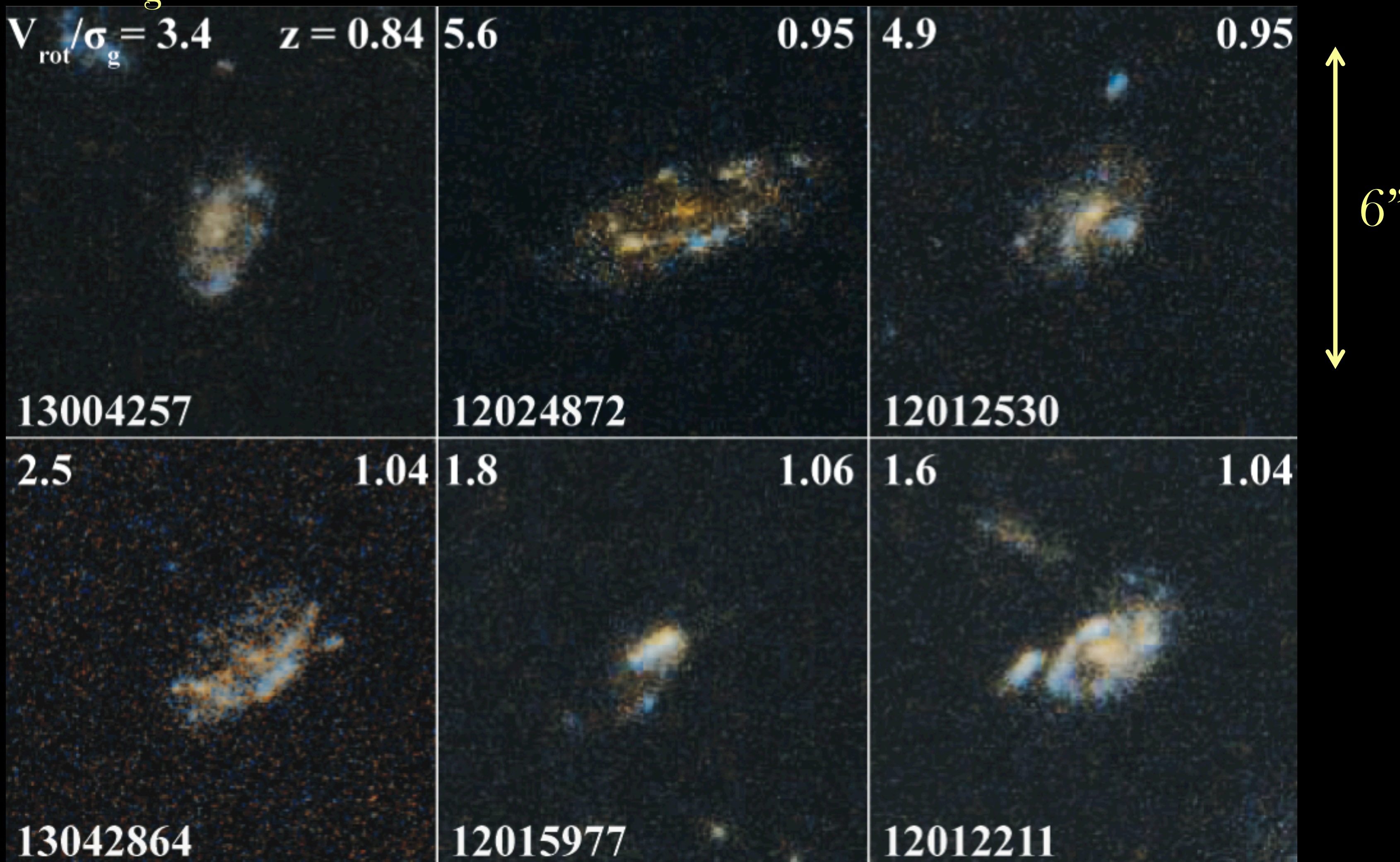
When is a disk galaxy *settled*?

Settled: $V/\sigma_g > 3$



Not Settled: $V/\sigma_g < 3$

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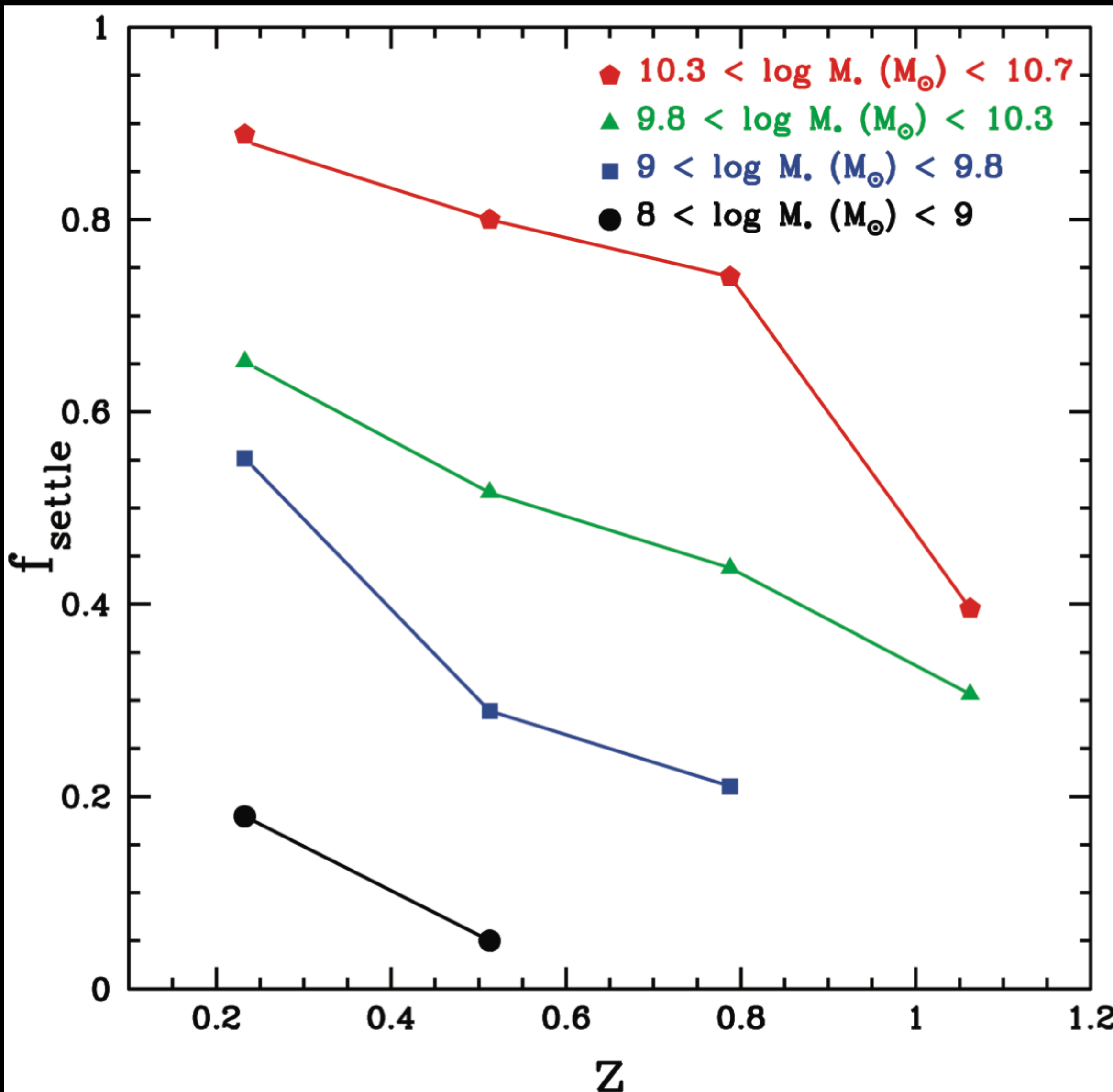
Fraction of Settled Galaxies with Redshift



- $f_{settled}$ ≡ fraction of galaxies with $V/\sigma_g > 3$
- Settled fraction increases with time
- The more massive a galaxy population is, the more settled it is at any z
- Same qualitative behavior for thresholds $1 < V/\sigma_g < 4$

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What Processes Cause Disk Settling/Formation?

1. Mergers, minor & major, rile up disks (e.g., Covington+10).

2. Mass accretion might also disturb disks (e.g., Bournaud+11, Cacciato+12)

Galaxies likely had larger gas reservoirs in the past:

3. Should cause more SF => more feedback

4. Violent disk instabilities (e.g., Bournaud+11, Cacciato+12)

The process(es) responsible need to decline earlier in more massive systems.

Conclusions

1. Most disk galaxies *not* in their final state at z~1.
    - they have significant disturbed motions and morphologies

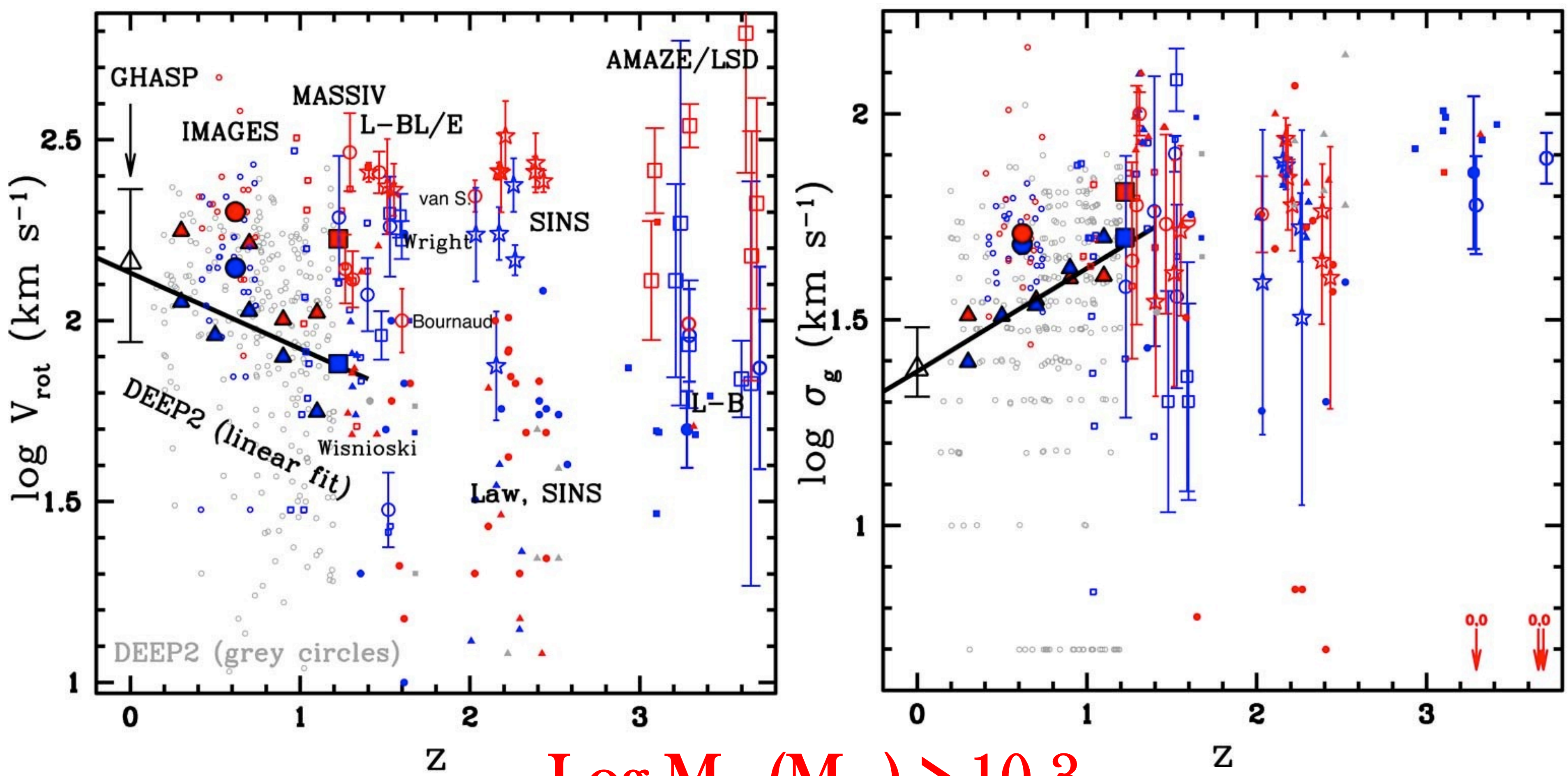
2. Galaxies increase in V_{rot} & $S_{0.5}$ and decrease in σ_g with time.

3. The more massive a galaxy is, the more kinematically ordered it is at any time.

What roles do minor/major mergers, feedback, and accretion play? How can simulations or SAMs be used to figure this out?

We are essentially seeing the creation of the Hubble Sequence for disk galaxies.

Comparison to other surveys of blue galaxy kinematics



Log M* (M☉) > 10.3

Log M* (M☉) < 10.3

no M* measurement