The Assembly of Disk Galaxies

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NGC 6984, credit: ESA/Hubble & NASA

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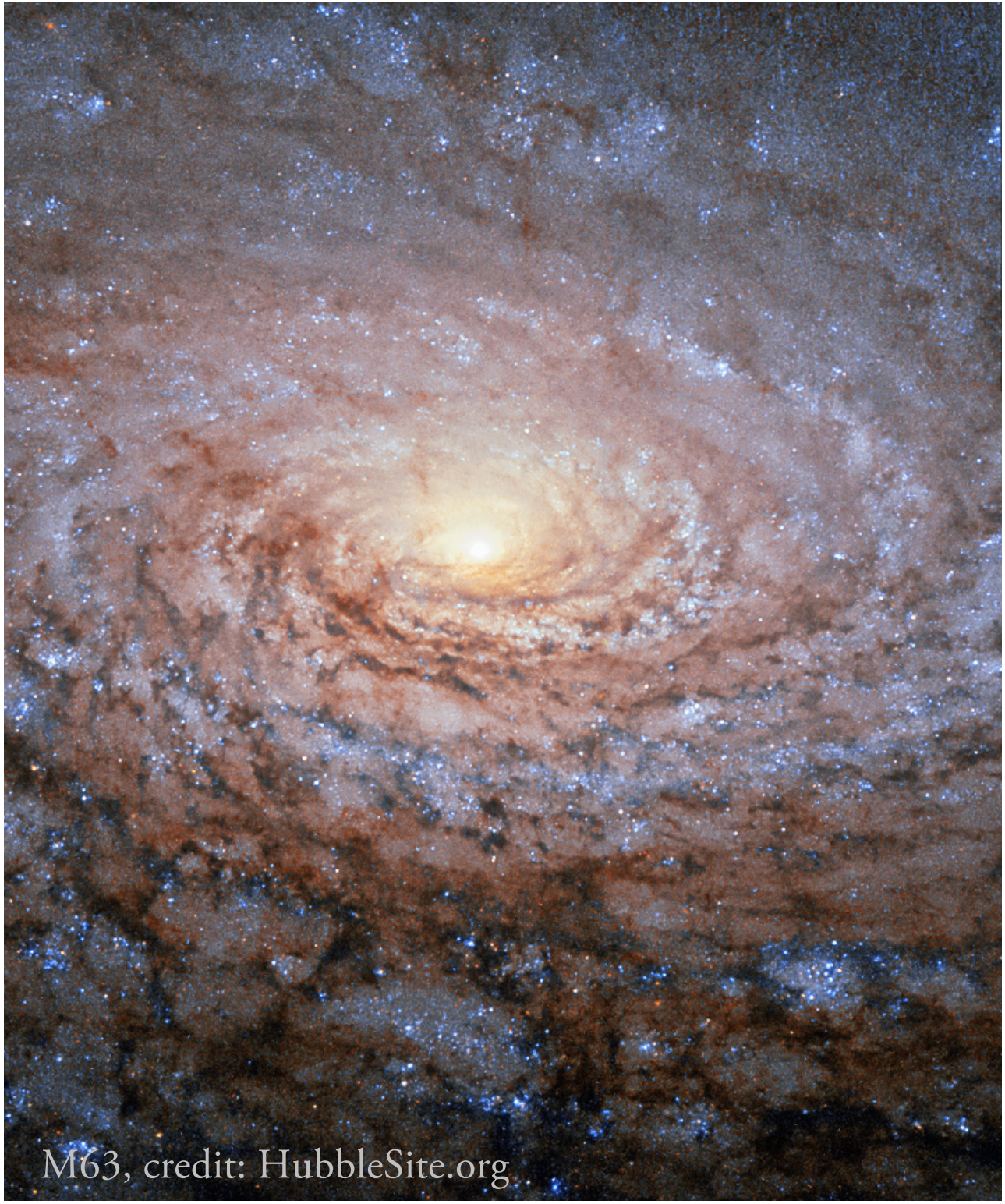
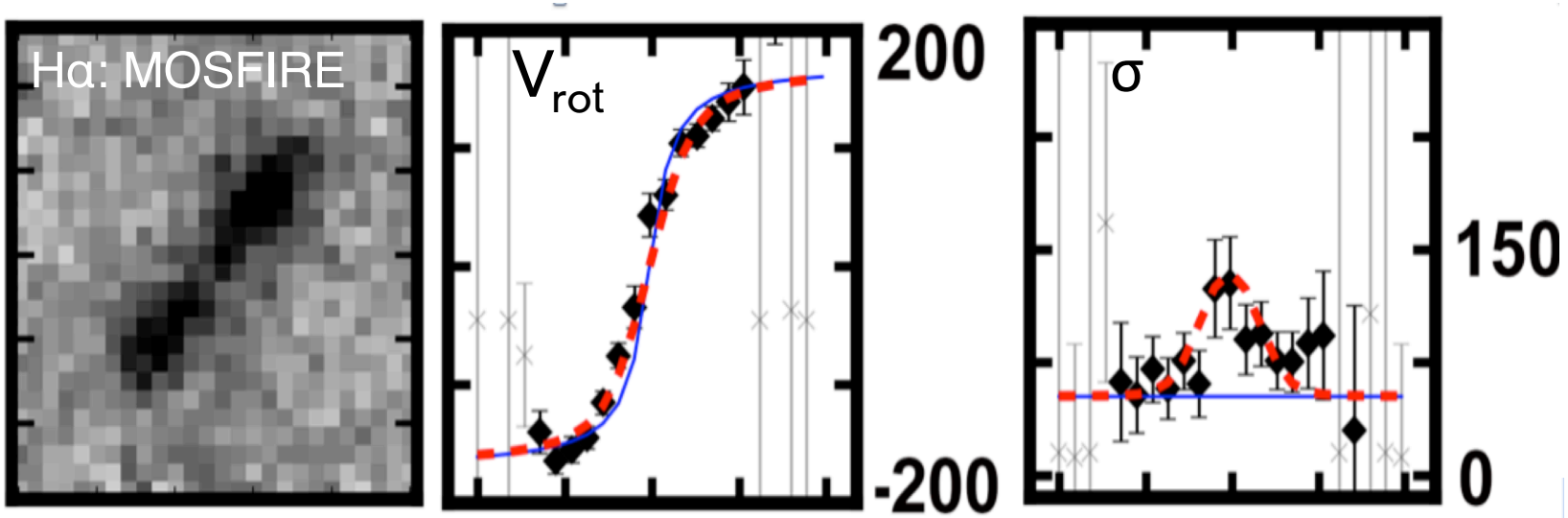
- SIGMA survey of galaxy kinematics at z=2
- Mock observations of galaxy simulations



When/how are disks assembled?

When/how do disks settle into their current well-ordered state?

Measurements of the kinematics of high z galaxies

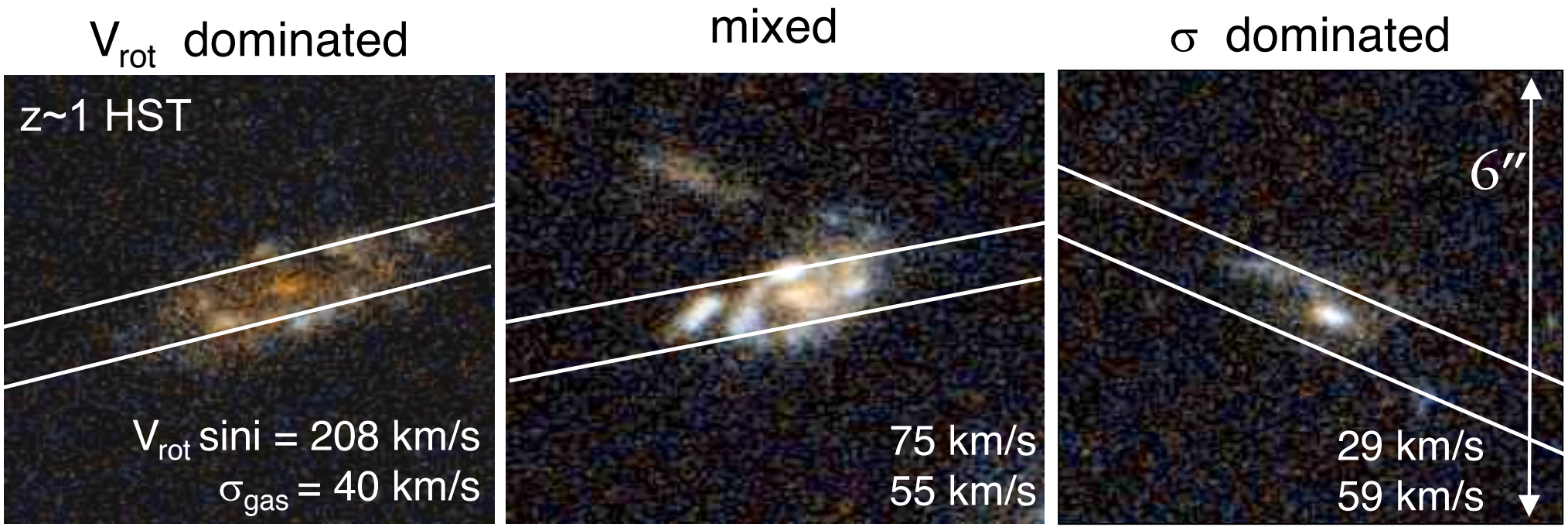


V_{rot} and σ are measured from emission lines in Keck spectra

It is important to take into account the effects of seeing and beam smearing when measuring galaxy kinematics.

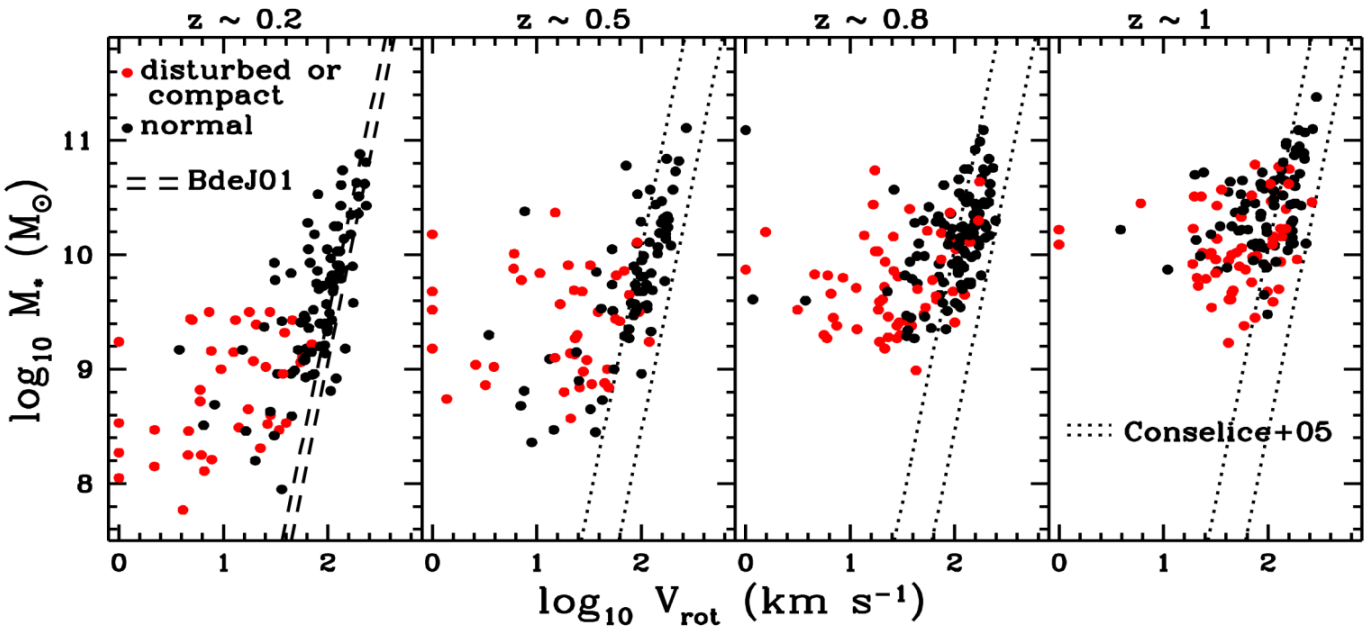
Weiner et al. 2006a,b; Kassin et al. 2007,12; Covington, Kassin et al. 2010; Simons, Kassin et al. 2016

Measurements of the kinematics of high z galaxies tell us about their physical state



σ is a *gas* velocity dispersion

- integrates over all velocity gradients beneath the seeing
- quantifies the amount of disordered motions in galaxies (Weiner et al. 06, Kassin et al. 2007, Covington, Kassin et al. 2010, Kassin et al. 14)
- Does not indicate a "thick disk" (i.e., a disk that is simply puffier)



Stellar Mass Tully-Fisher Relation to z=1.2

coincident with Faber-Jackson

$$S_{0.5} = \sqrt{0.5V_{rot}^2 + \sigma_{gas}^2}$$

$S_{0.5}$ takes into account all the motions, not just rotation.

$S_{0.5}^2$ ~ total mass (see also Covington et al. 2010)

Kassin et al. 2007,12

Tully-Fisher Relation at z~0.2

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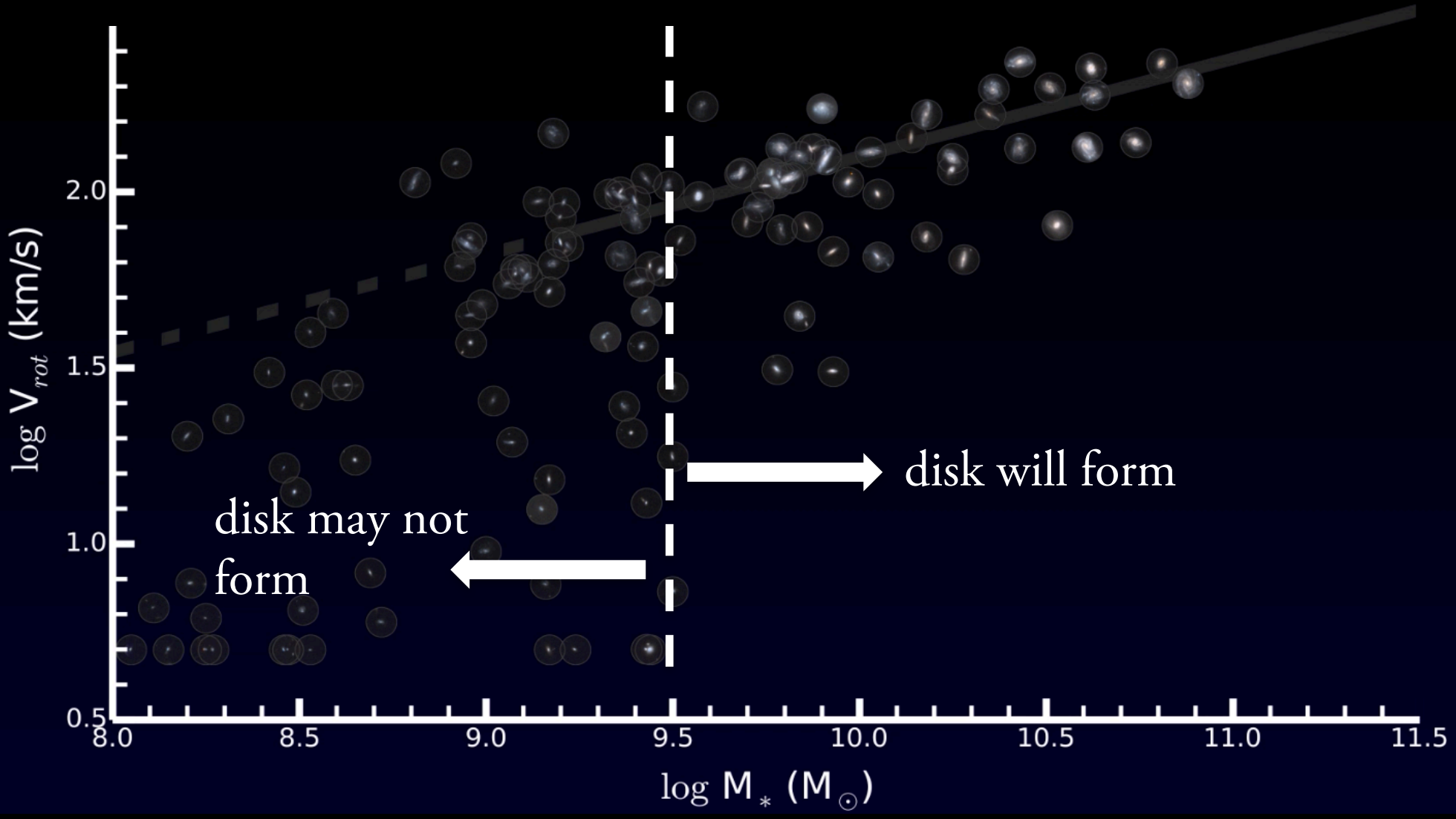
Ordered disks lie on ridge-line, Disturbed galaxies lie off

“Mass of Disk Formation”



Simons, Kassin et al. 2015 et al.

Tully-Fisher Relation at z~1.0

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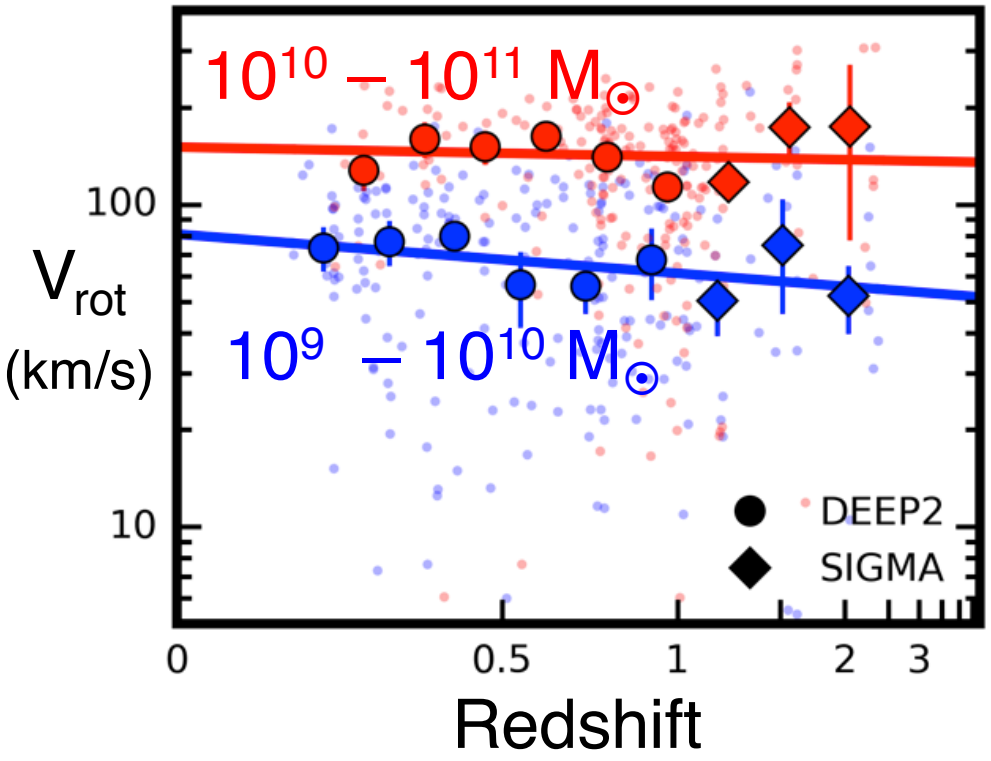
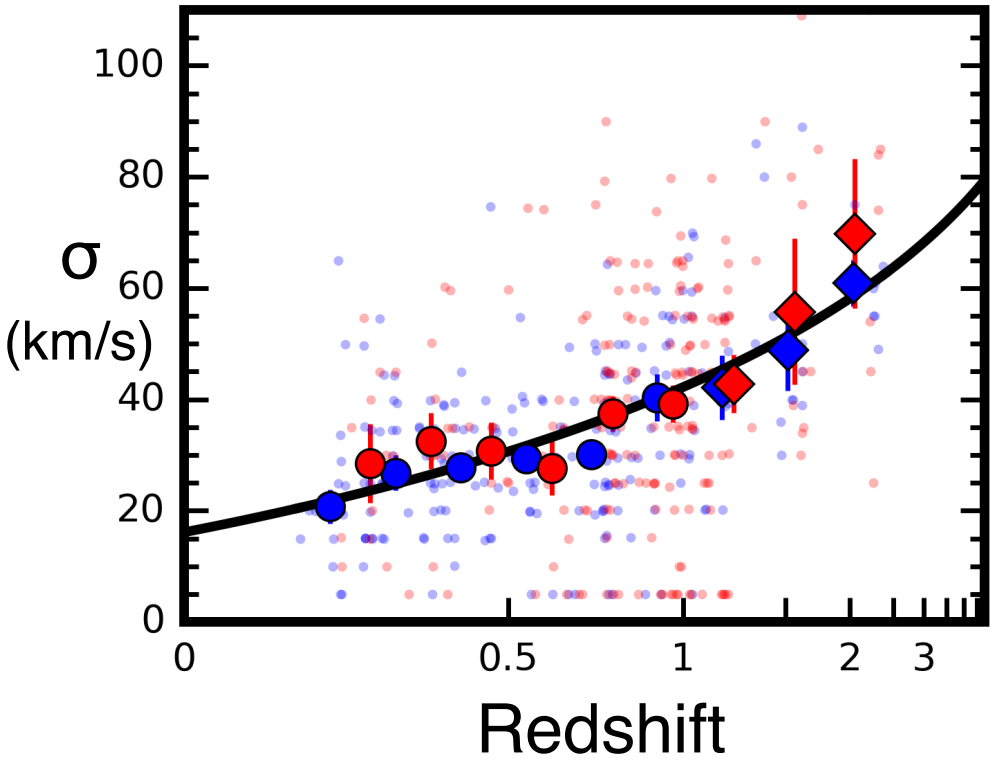
High-z Galaxies are Mostly Peculiars
Still, more Ordered disks lie on ridge-line & more Disturbed galaxies lie off

Does the relative importance of V_{rot} and σ evolve with time?





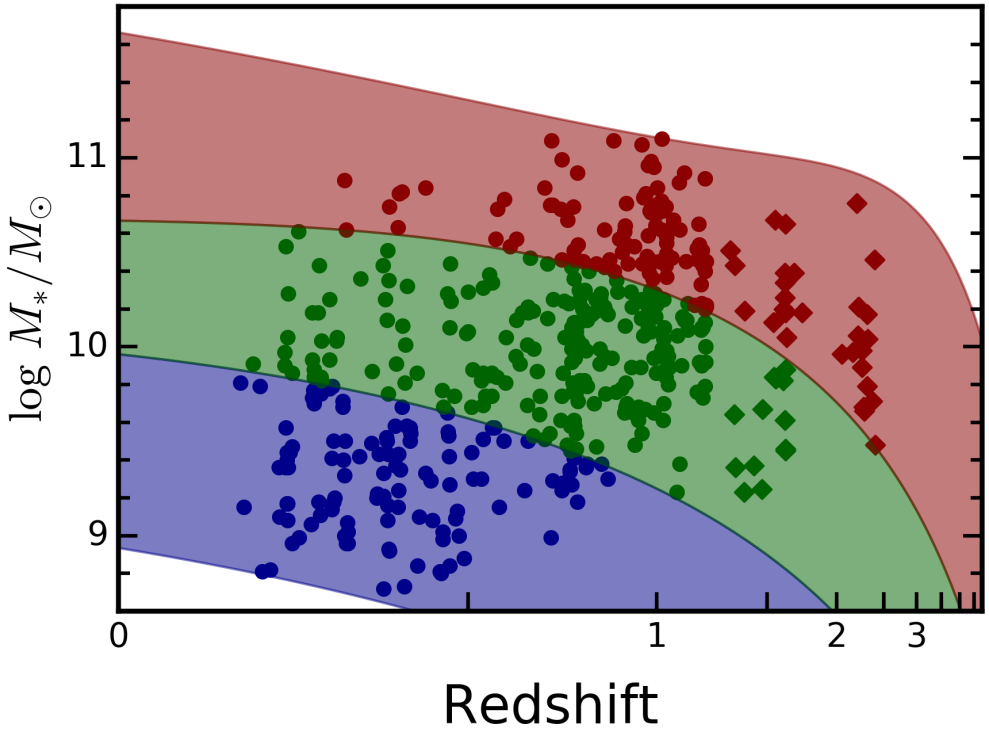
"Disk Settling"

$\log \sigma = -0.84\,(1+z)^{-1} + 2.04$

Kassin et al.12

Simons, Kassin et al. 2016 & 17

σ trend see also Wisnioski et al. 15, Turner et al. 2017



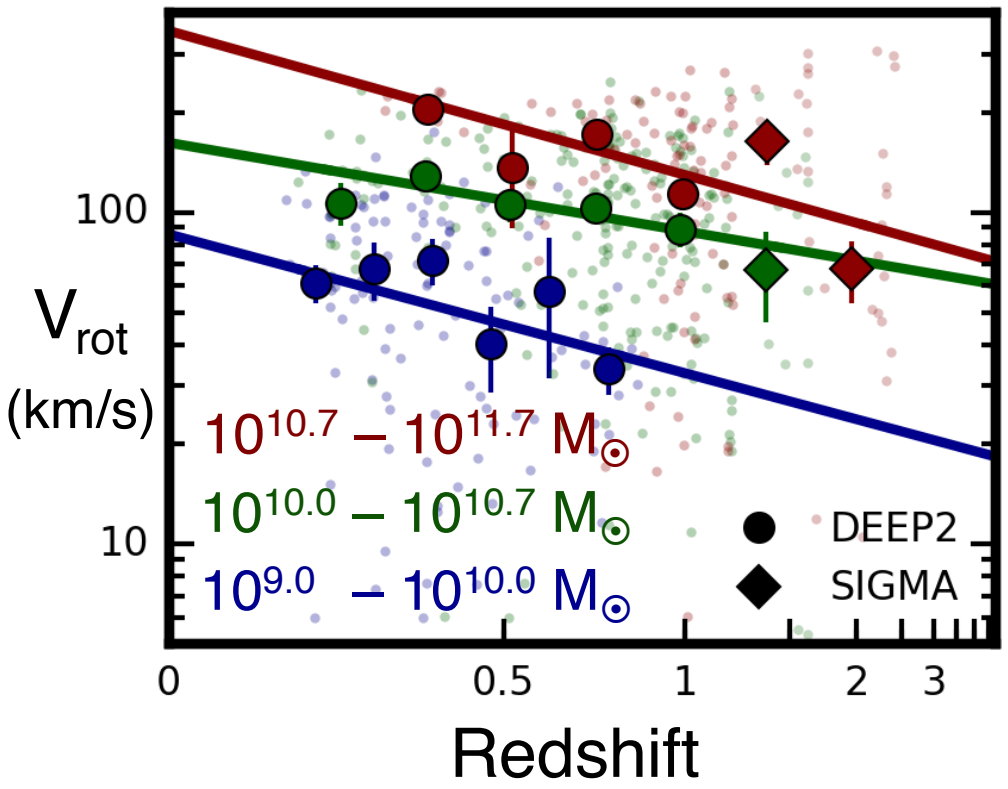
$10^{10.7}$ – $10^{11.7}$ $M_\odot$

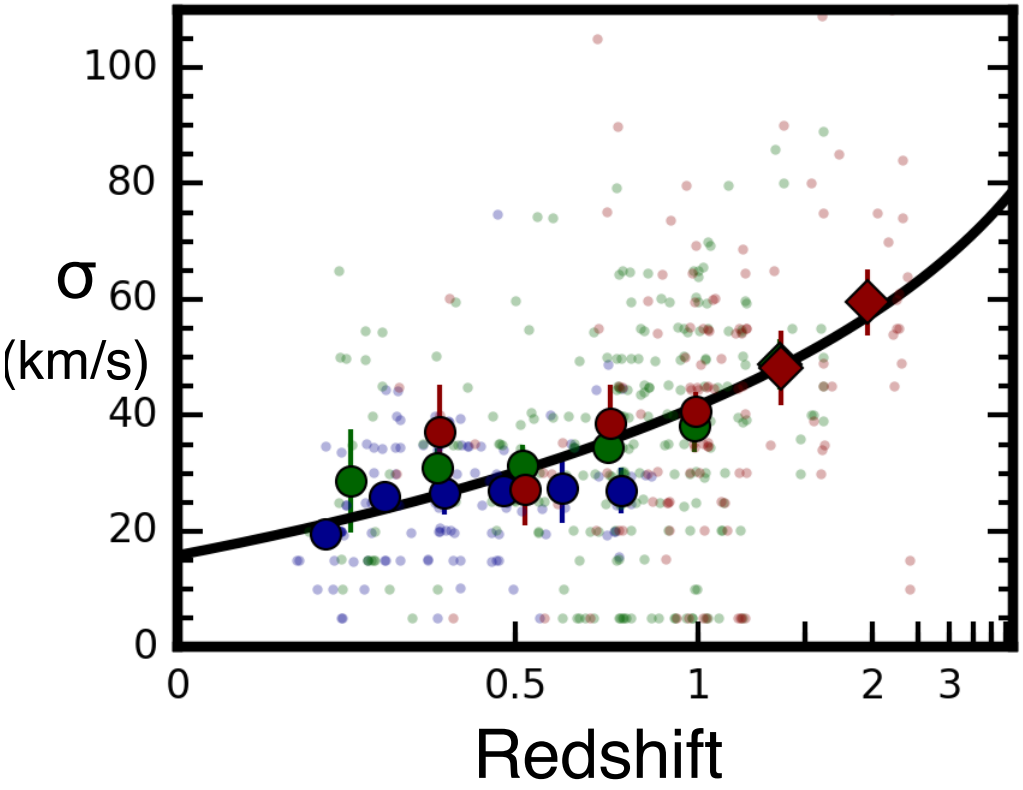
10^{10} – $10^{10.7}$ $M_\odot$

10^{9} – 10^{10} $M_\odot$

Linking galaxy populations in time with "abundance matching"

(our best shot, but far from perfect)

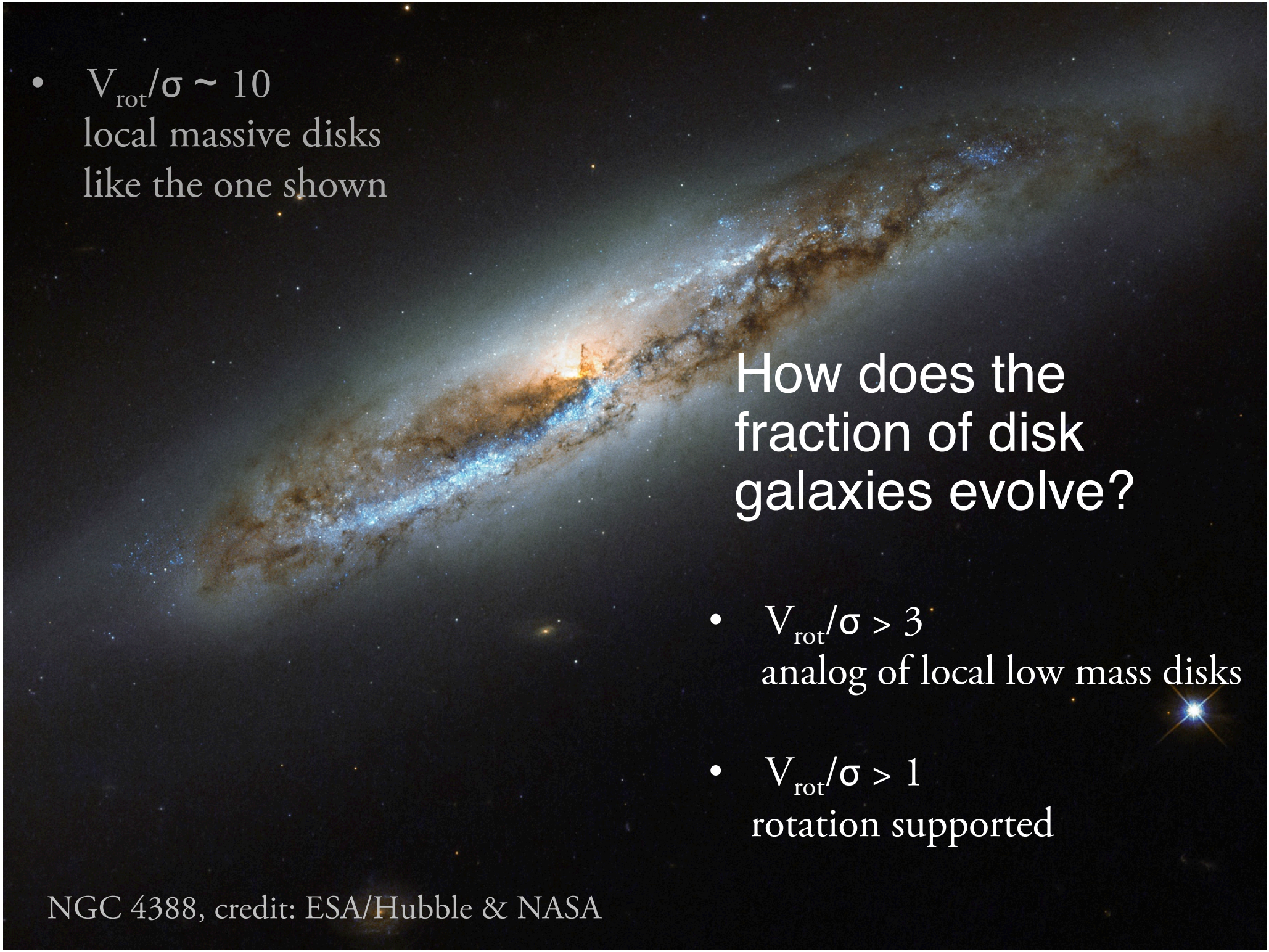


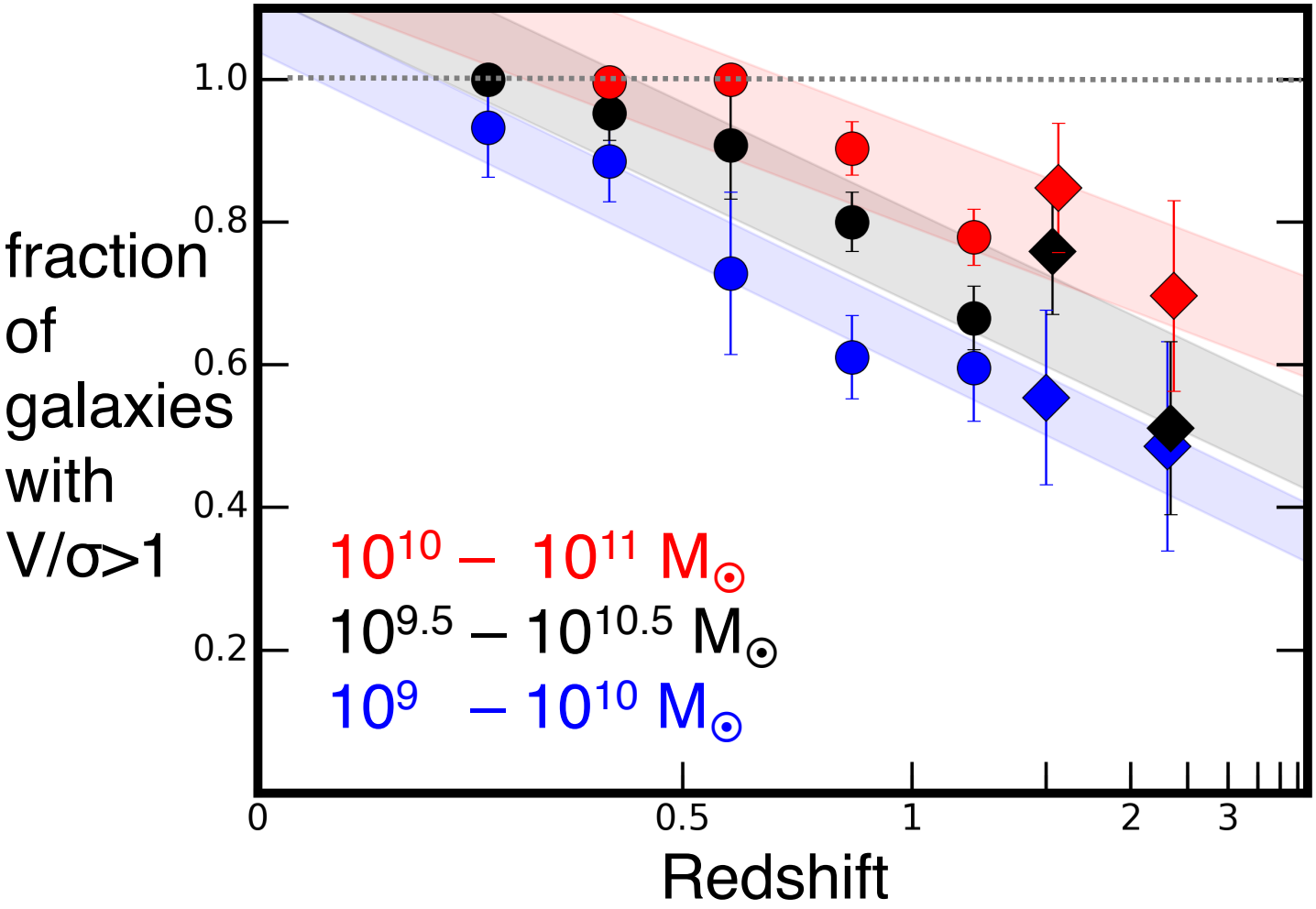


"Disk Settling"

Abundance matched galaxy populations
(Moster et al. 2013)

Kassin et al. 2012
Simons, Kassin et al. 2017


• $V_{rot}/\sigma \sim 10$
local massive disks
like the one shown
How does the fraction of disk galaxies evolve?
• $V_{rot}/\sigma > 3$
analog of local low mass disks
• $V_{rot}/\sigma > 1$
rotation supported
NGC 4388, credit: ESA/Hubble & NASA

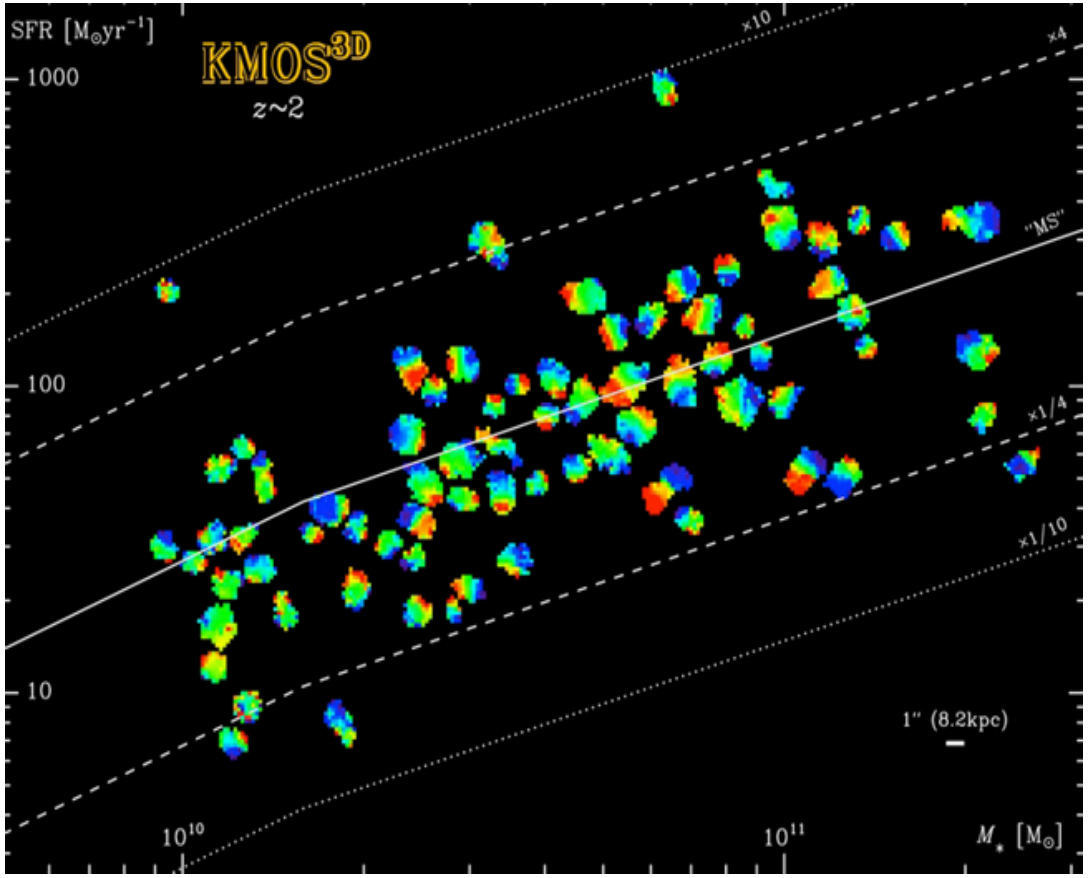


"Disk Settling"

Fraction of galaxies with $V_{rot}/\sigma>1$ increases with time

Kassin et al.12;
Simons, Kassin et al. 2016 & 17

Large IFU surveys of galaxy kinematics



SFR ($M_\odot$/yr)

stellar mass ($M_\odot$)

z~3:

- AMAZE/LSD: Gnerucci et al. 2011
- KDS: Turner et al. 2017

z~2:

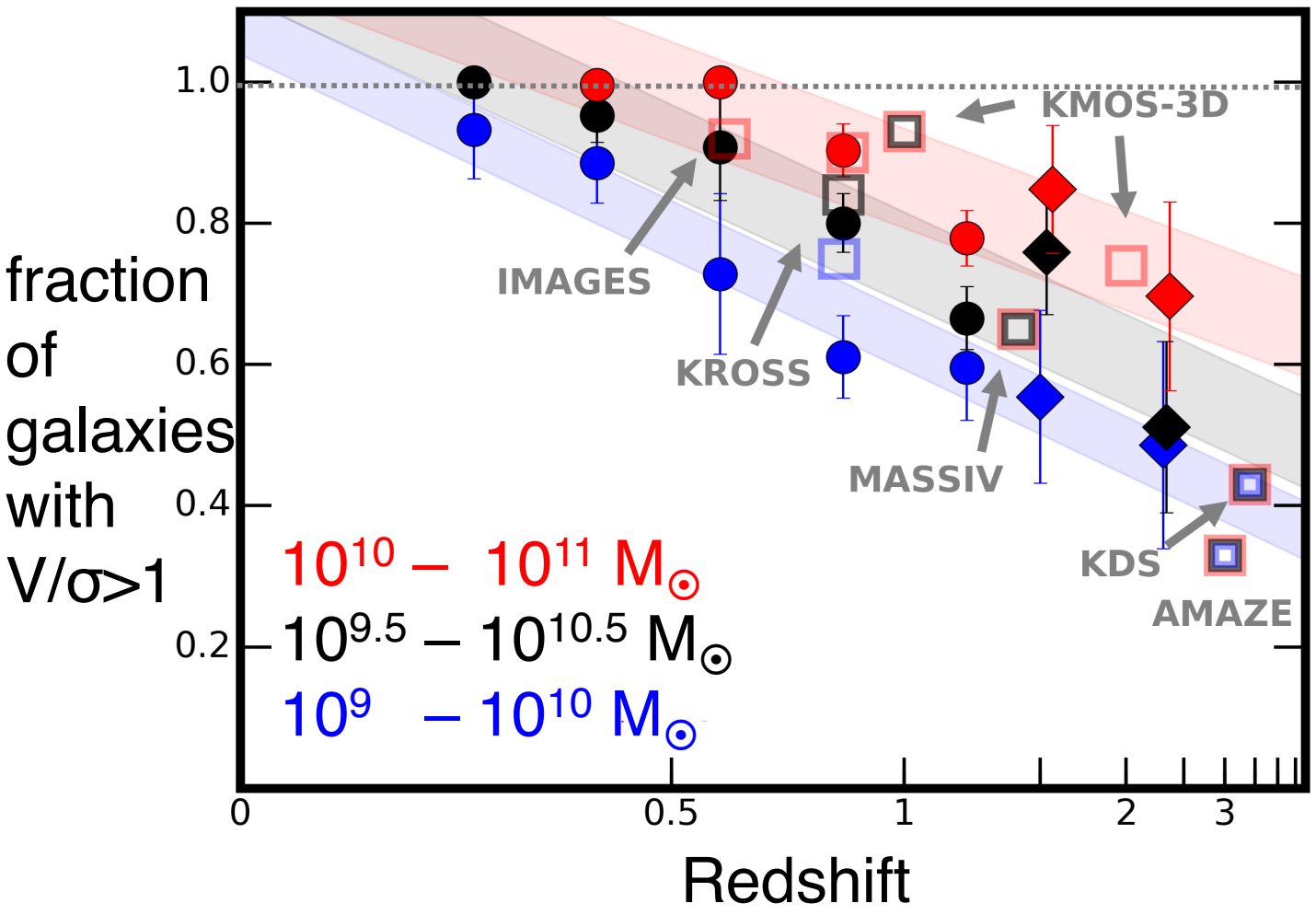
- KMOS^{3D}: e.g., Wisnioski et al. 2015
- SINS: e.g., Förster-Schreiber et al. 2006,9,11

z~1:

- MASSIV: e.g., Epinat et al. 2012
- KROSS: e.g., Madgis et al. 2016, Harrison et al. 2017
- KMOS$^{3D:}$ e.g., Wisnioski et al. 2015

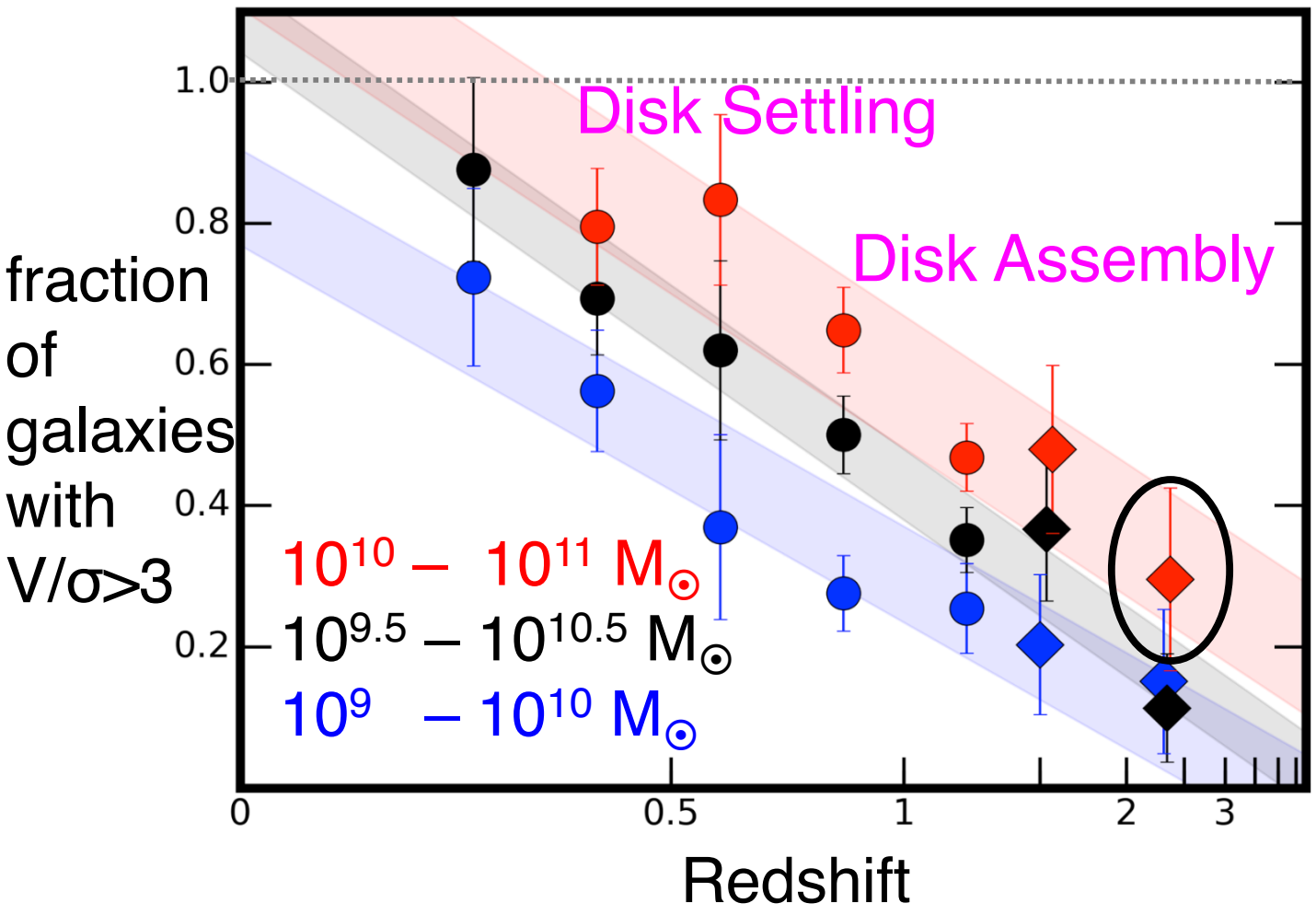
z<1

- IMAGES: e.g., Flores et al. 2006, Yang et al. 2008, Puech et al. 2008



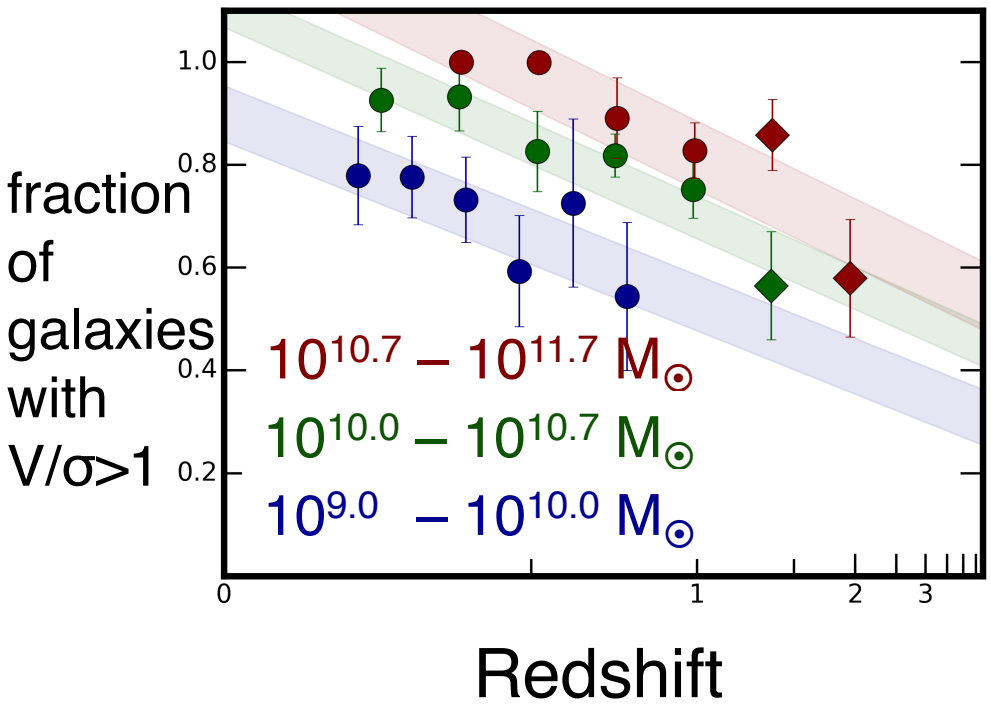
Quantitatively, surveys agree that disks become more ordered with time

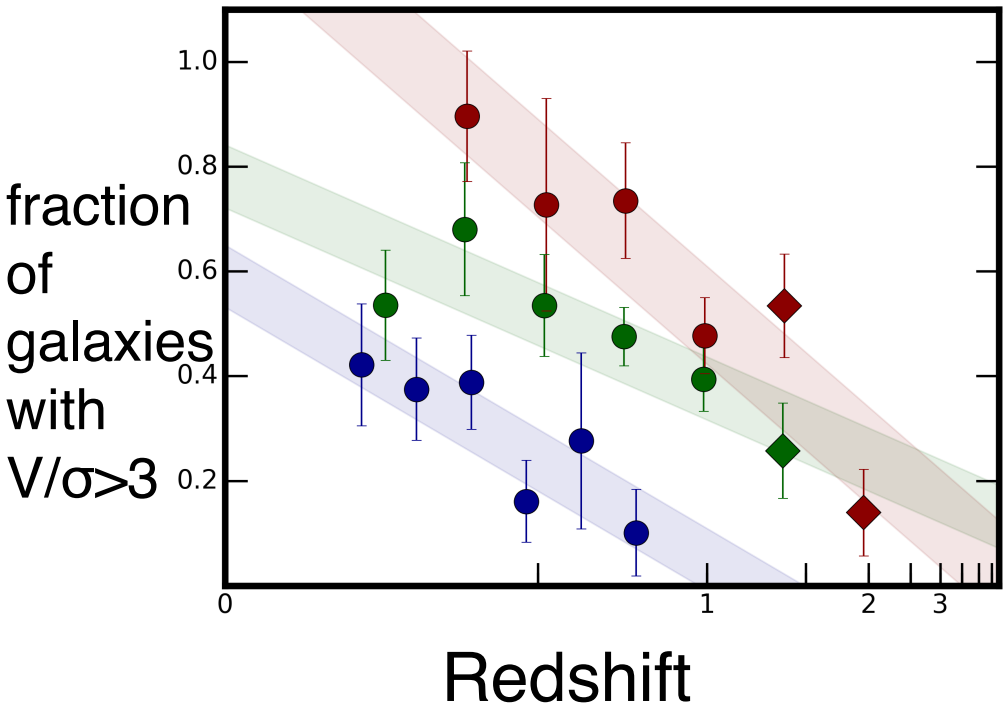
Kassin et al.12;
Simons, Kassin et al. 2016 & 17



Only ~30% of high mass galaxies at z=2 have V/σ > 3!

Kassin et al.12;
Simons, Kassin et al. 2016 & 17

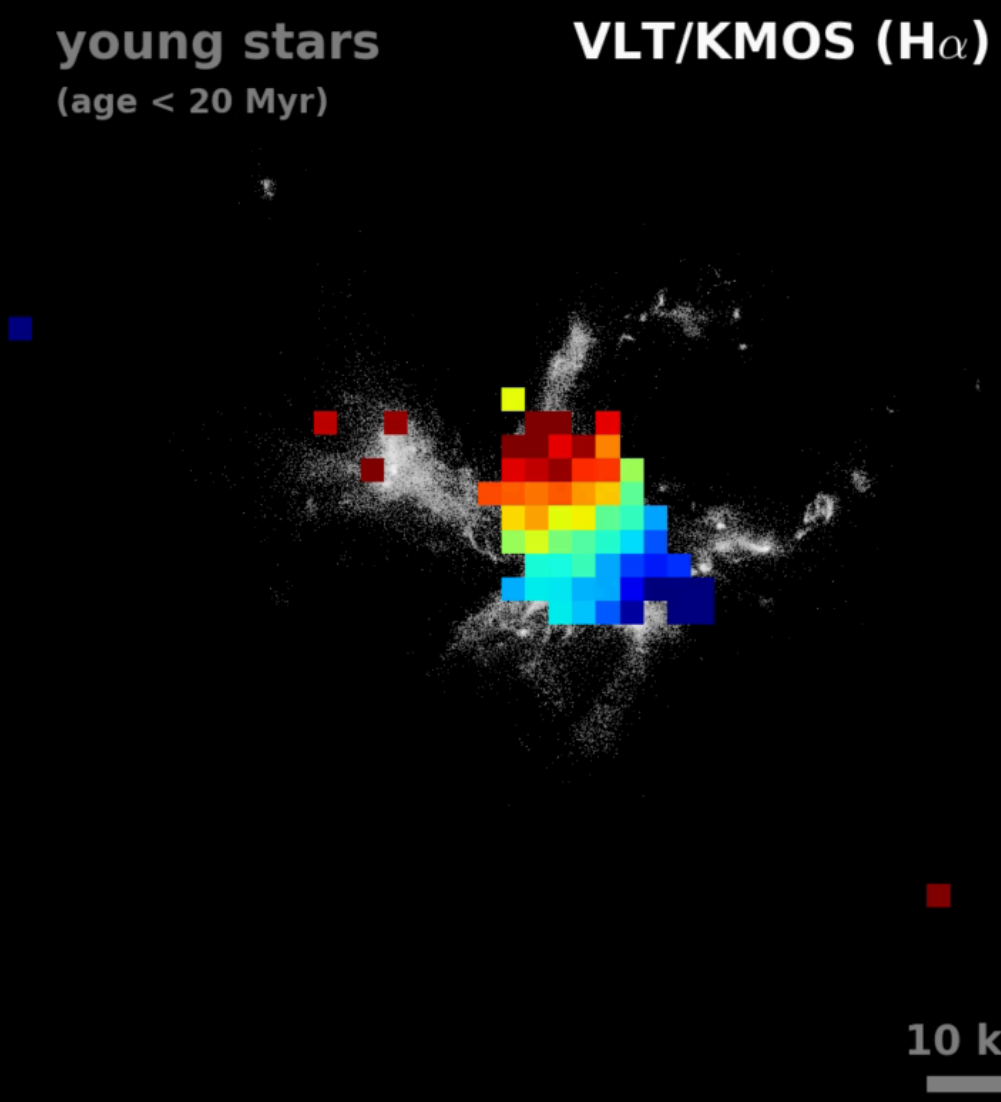




"Disk Settling"
"Disk Assembly"

Abundance matched galaxy populations

Kassin et al.12;
Simons, Kassin et al. 2016 & 17

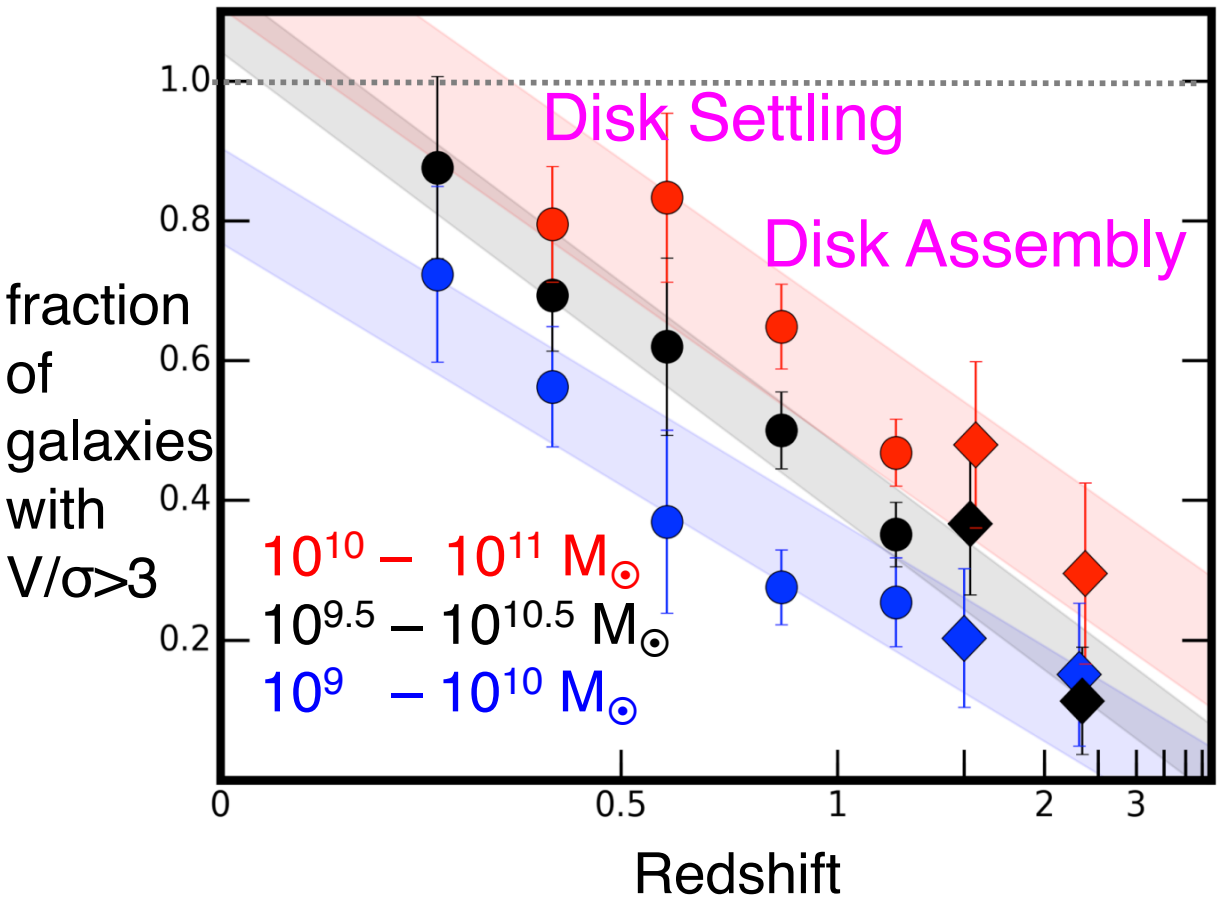


V_{rot} can be confused with orbital rotation of mergers in ground-based observations

=> Fraction of disks at z~2 defined using V/σ is likely even lower

VELA simulation
(Ceverino et al. 2014, 16)

Simons, Kassin,
Snyder, Ceverino+ in prep



Conclusions:

- the vast majority of galaxies at high redshift are not disks
- galaxies increase in ordered rotation (V_{rot}) and decrease in disordered motions (σ) with time
- the average fraction of disk galaxies increases significantly with time
- higher mass galaxies arrive at an ordered state first ("kinematic downsizing")
- conclusions from high-z kinematic surveys depend on sample selections for mass and morphology