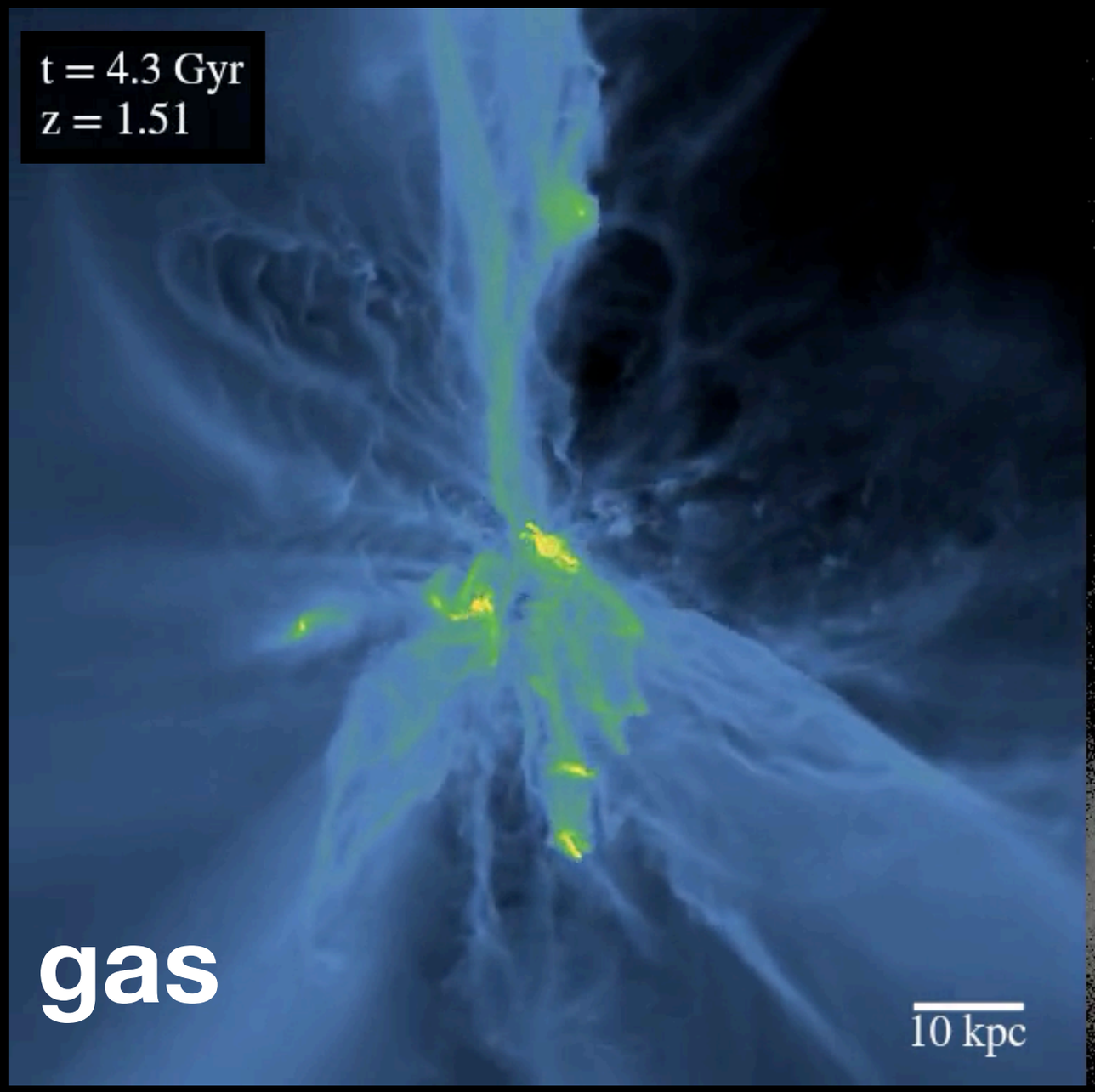
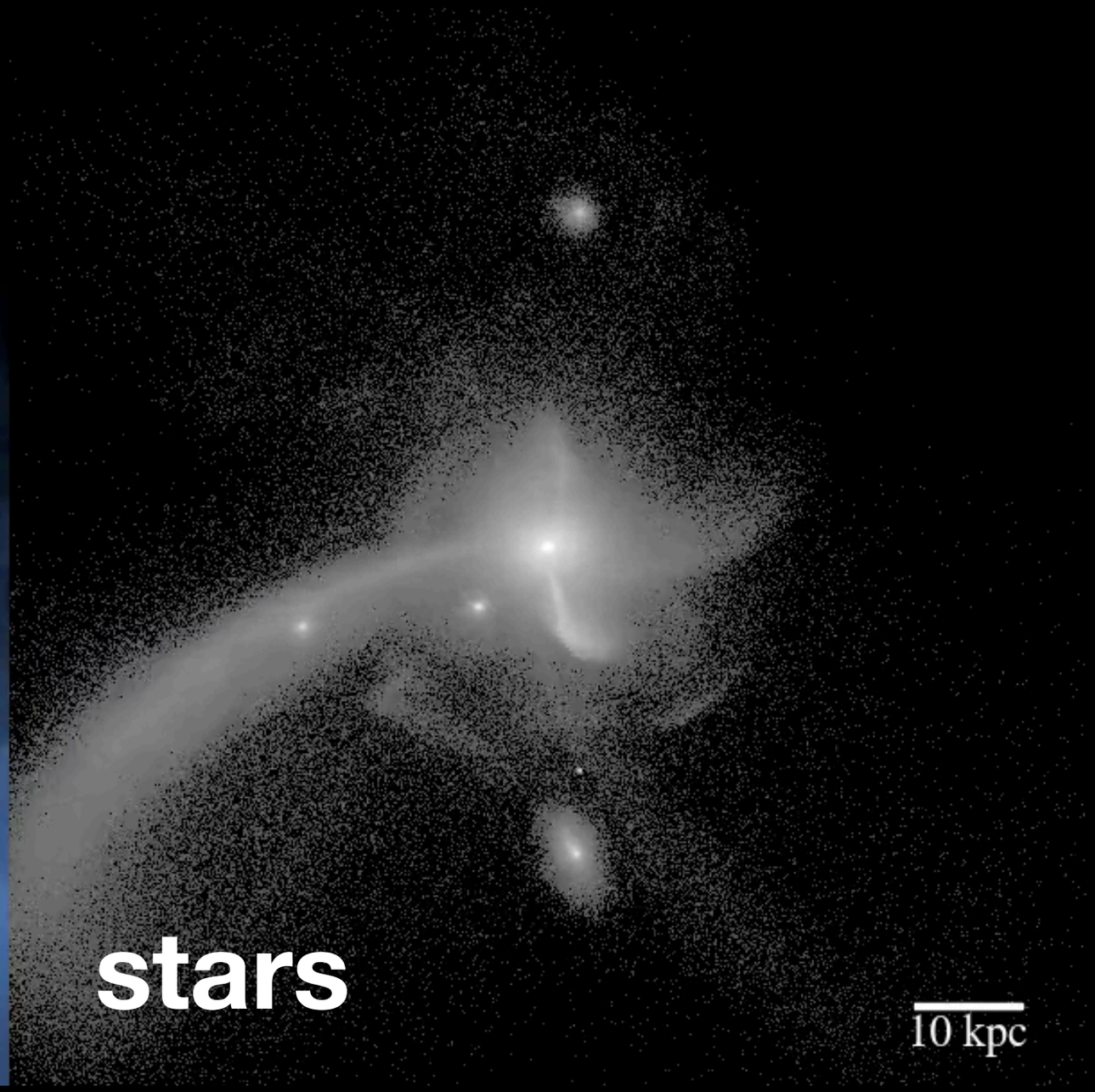
Bridging Observations with Simulations in the Era of Extremely Big Telescopes

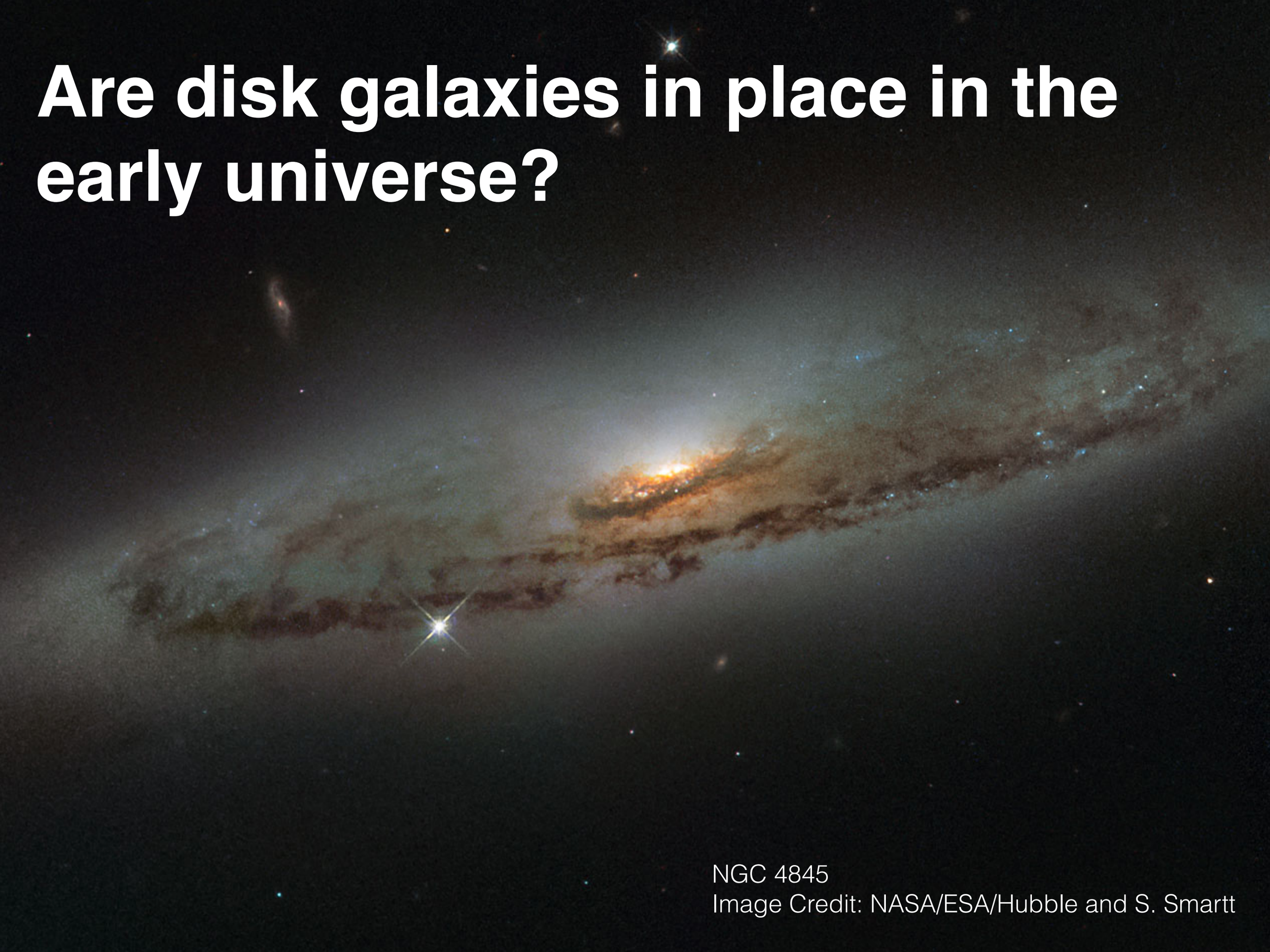




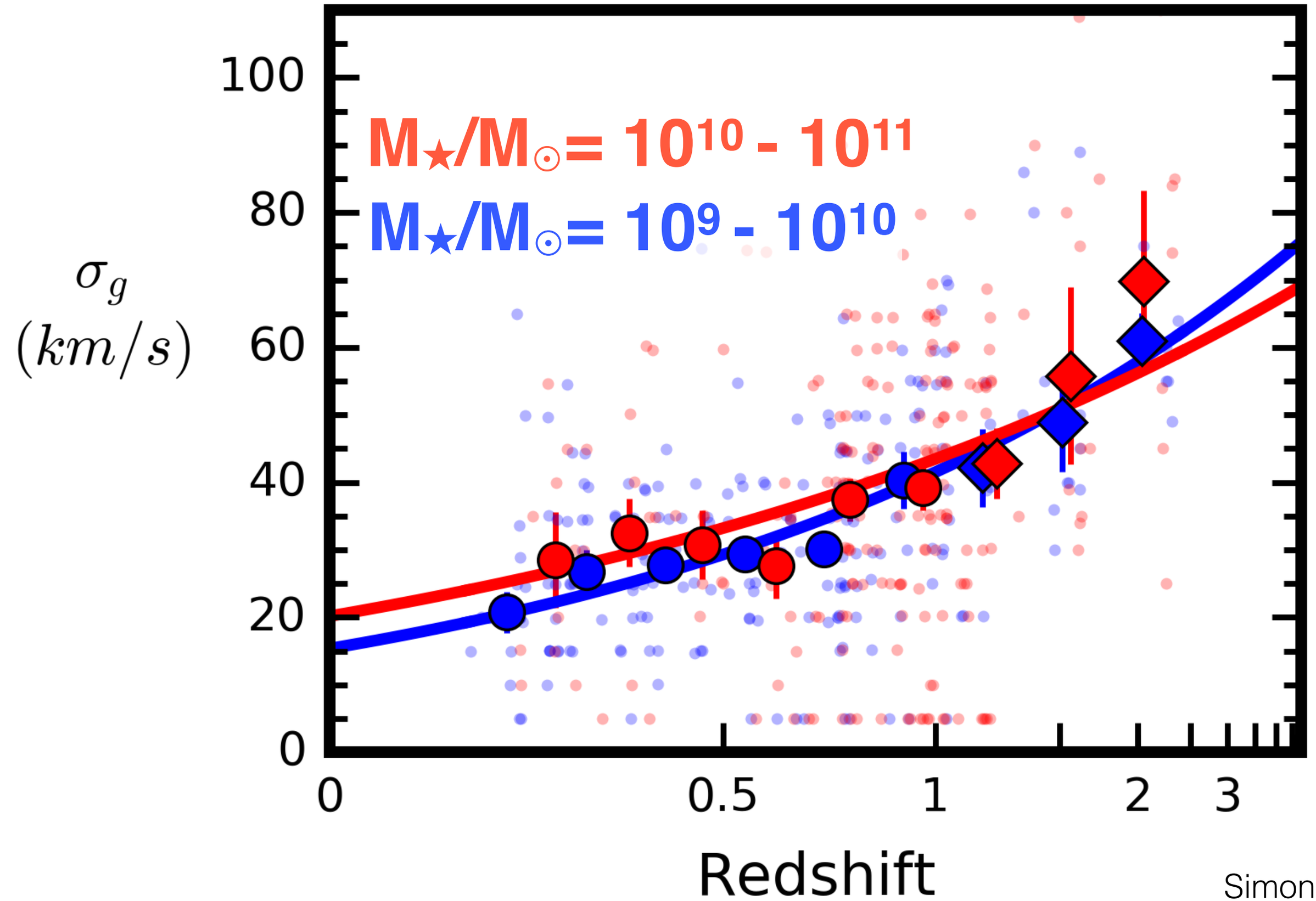
Raymond C. Simons
Giacconi Fellow, STScI

FOGGIE simulations
Peeples+ 19, Corlies+19

Are disk galaxies in place in the early universe?



NGC 4845
Image Credit: NASA/ESA/Hubble and S. Smartt



Simons+17

see also, e.g., Wisnioski+ 15

DEEP2 (0 < z < 1.2): Kassin+12

SIGMA (1.3 < z < 2.5): Simons+16

fraction of star-forming galaxies with $V_{rot}/\sigma_g > 3$

$M_\star/M_\odot = 10^{10} - 10^{11}$

$10^{9.5} - 10^{10.5}$

$10^{9} - 10^{10}$

1.0
0.8
0.6
0.4
0.2

0
0.5
1
2
3

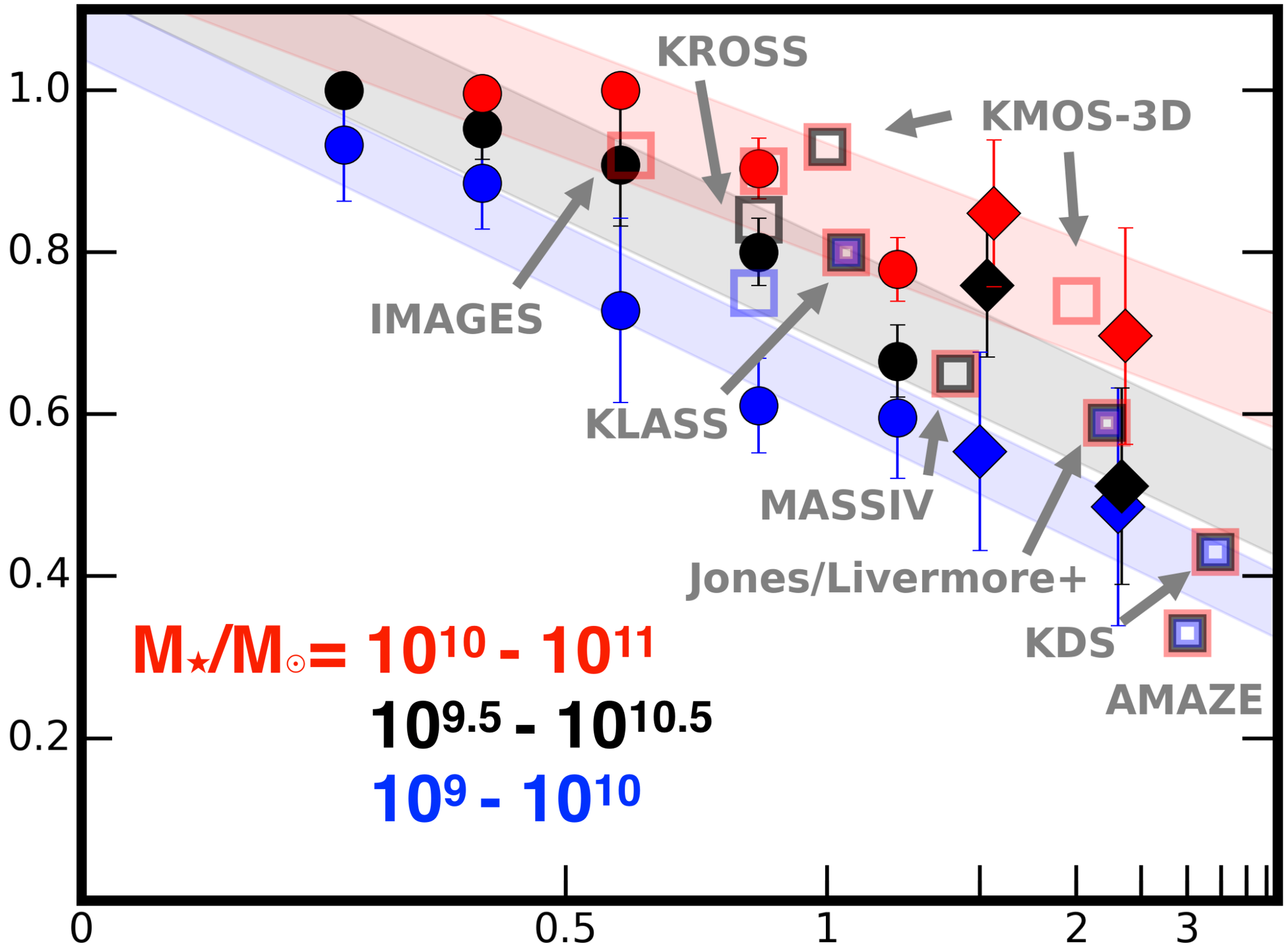
Redshift

Simons+17

DEEP2 ($0 < z < 1.2$): Kassin+12

SIGMA ($1.3 < z < 2.5$): Simons+16

fraction of star-forming galaxies with $V_{rot}/\sigma_g > 1$



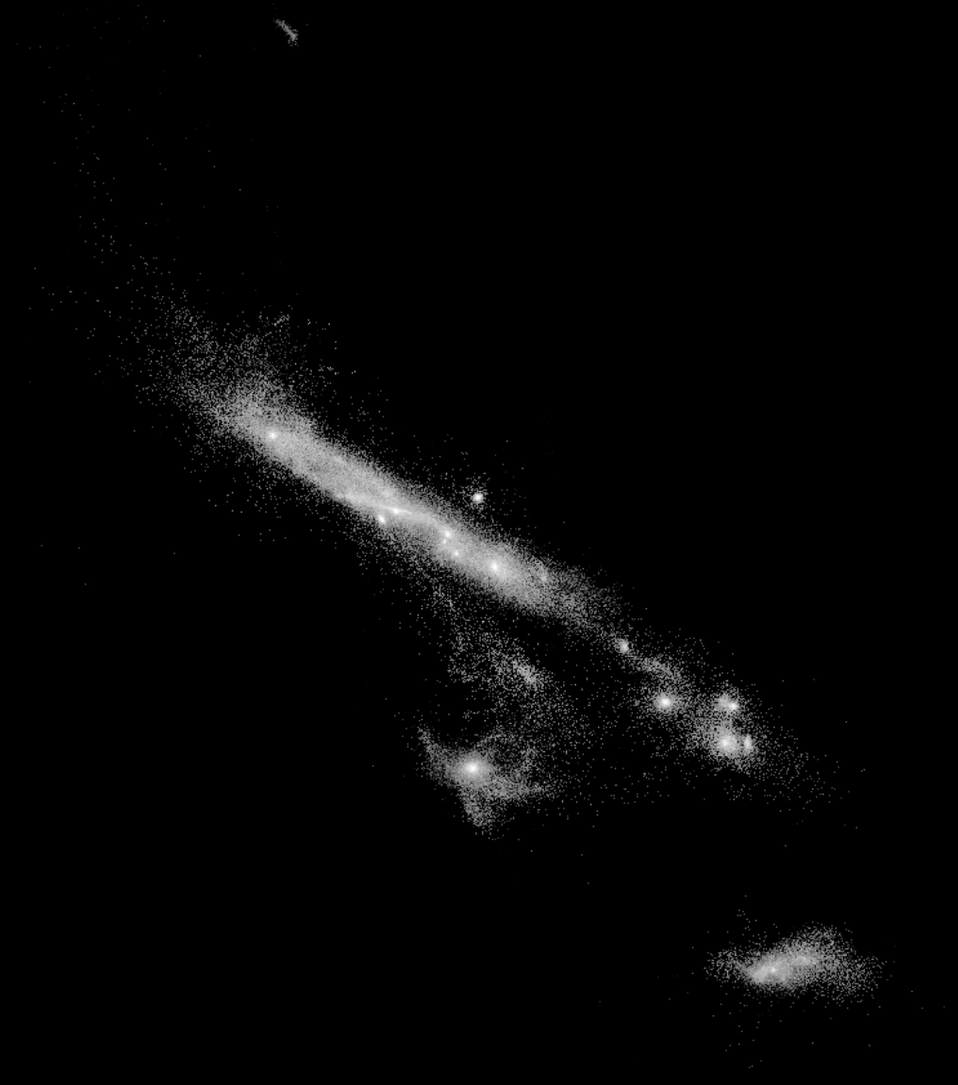
IMAGES: Puech+ 08
MASSIV: Vergani+ 12
KLASS: Mason+ 17
KROSS: Stott+16
KMOS-3D: Wisnioski+ 15
SINS: Förster Schreiber+ 09
AMAZE: Gnerucci+ 11
KROSS: Harrison+ 17
KDS: Turner+ 17
Lensed: Jones+ 10, Livermore+ 15

Simons+17
DEEP2 (0 < z < 1.2): Kassin+12
SIGMA (1.3 < z < 2.5): Simons+16

Is it safe to assume the **velocity gradients** observed in high redshift galaxies trace the **rotational motions** of disks?

Synthetic Observations of Hydro Simulations

simulated disk at z = 2
(VELA simulation suite)

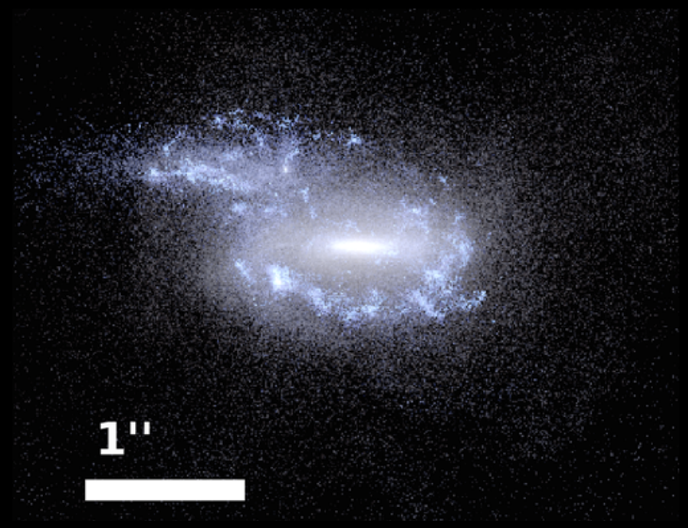


VELA Simulations: Ceverino+ 14

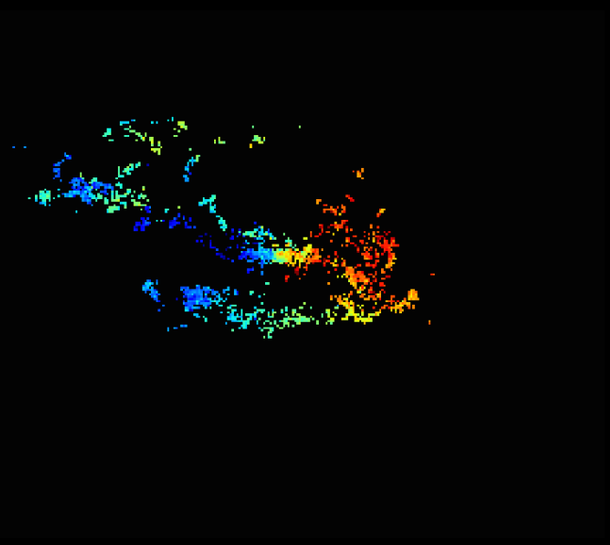
Synthetic Observations of Hydro Simulations

post processing:
SUNRISE dust radiative transfer

- MAPPINGS III model for star-forming regions
- 19 cameras placed around central galaxy



noiseless image



noiseless velocity map

VELA Simulations: Ceverino+ 14
SUNRISE: Jonsson+ 06,10, Jonsson & Primack 10
MAPPINGS III: Groves+08

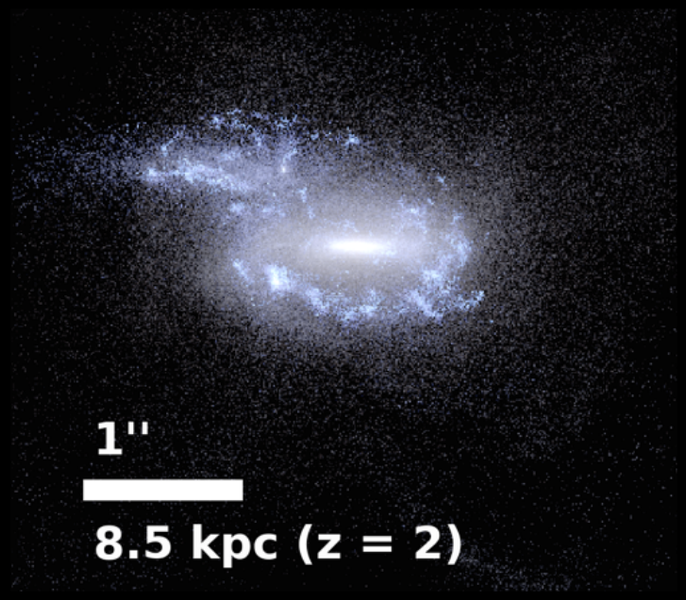
Synthetic Observations of Hydro Simulations

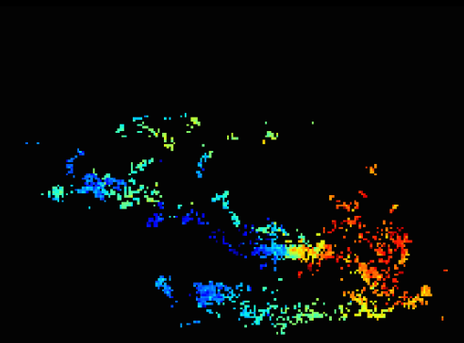
post processing:
SUNRISE dust radiative transfer

- MAPPINGS III model for star-forming regions
- 19 cameras placed around central galaxy

post-post processing:

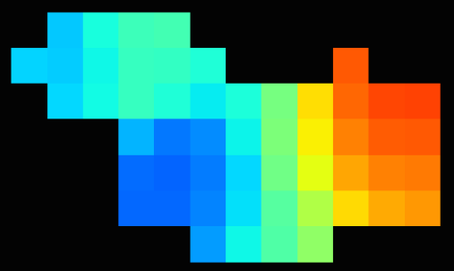
add surface brightness dimming, appropriate noise, spectral and spatial resolution





HST/WFC3

VLT/KMOS



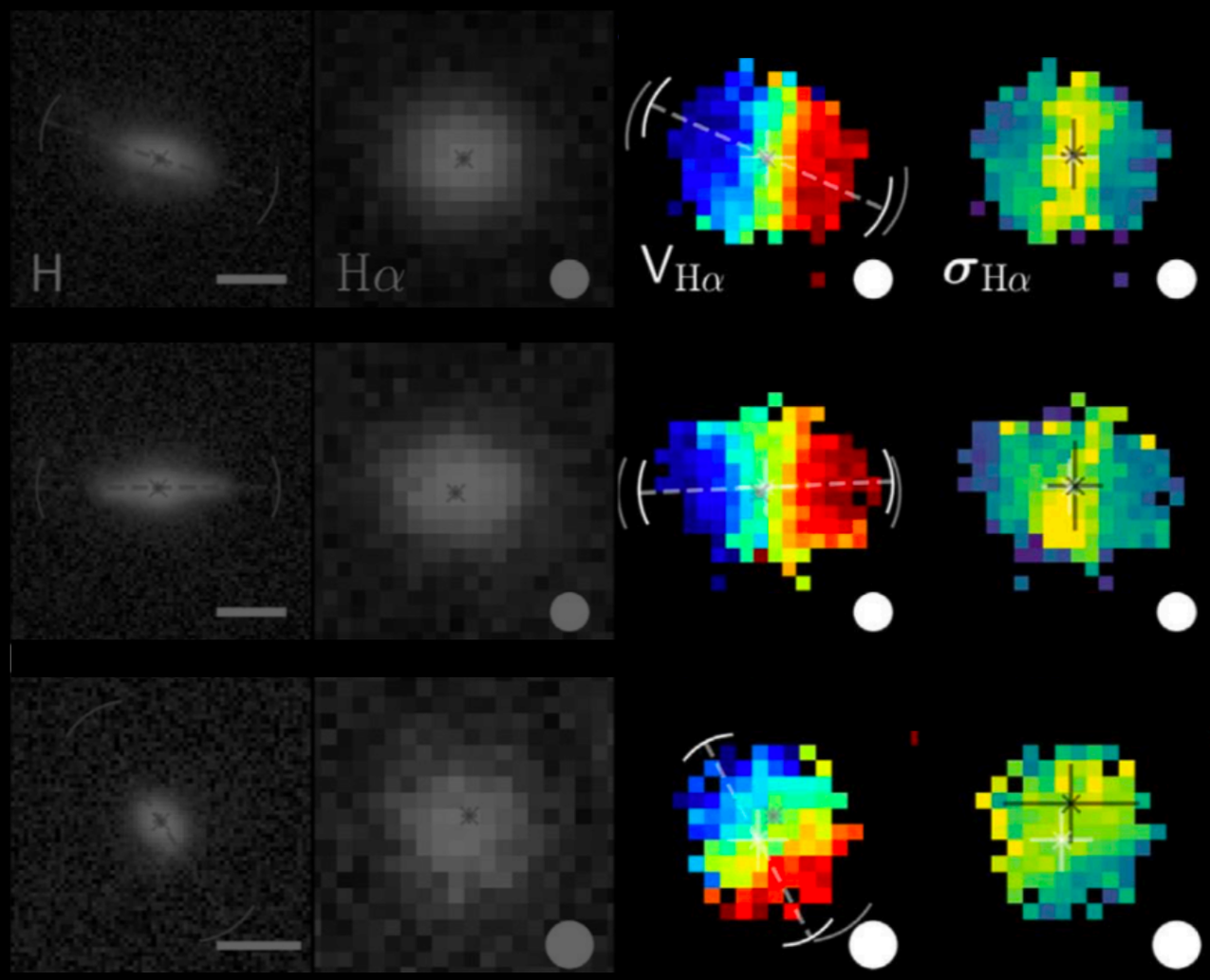
Seeing

synthetic *HST/JWST* images available at https://archive.stsci.edu/prepds/vela/

VELA Simulations: Ceverino+ 14
SUNRISE: Jonsson+ 06,10, Jonsson & Primack 10
MAPPINGS III: Groves+08

Disk galaxies

as determined from intrinsic kinematic properties



observational disk criteria

(Wisnioski+ 15; KMOS-3D)

1. continuous single V gradient
2. $V_{Ha,vot} > \sigma_{Ha}$
3. steepest V gradient coincident with peak in σ map
4. aligned photometric and kinematic axes
5. steepest V gradient coincident with continuum center

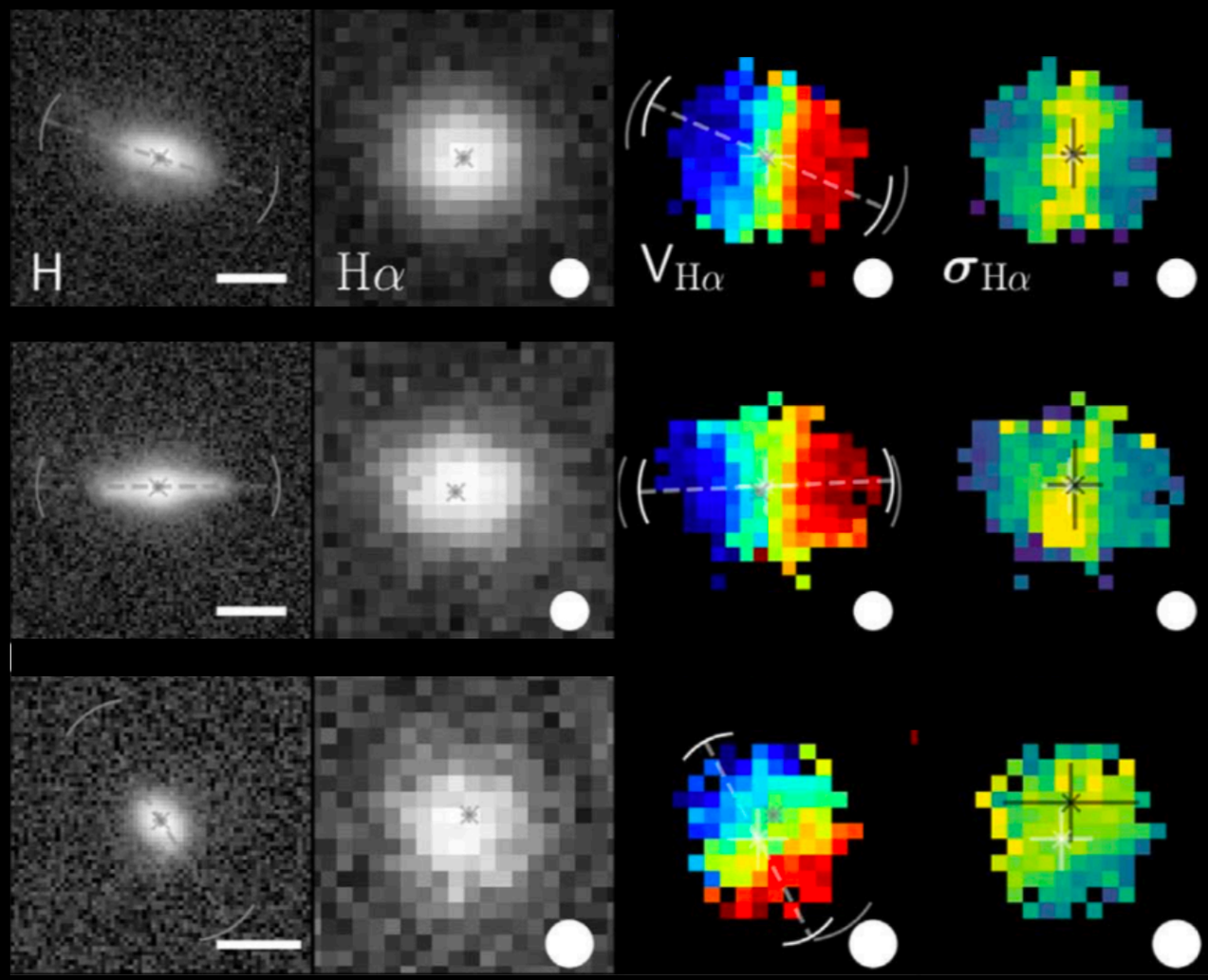
Simons+ 19

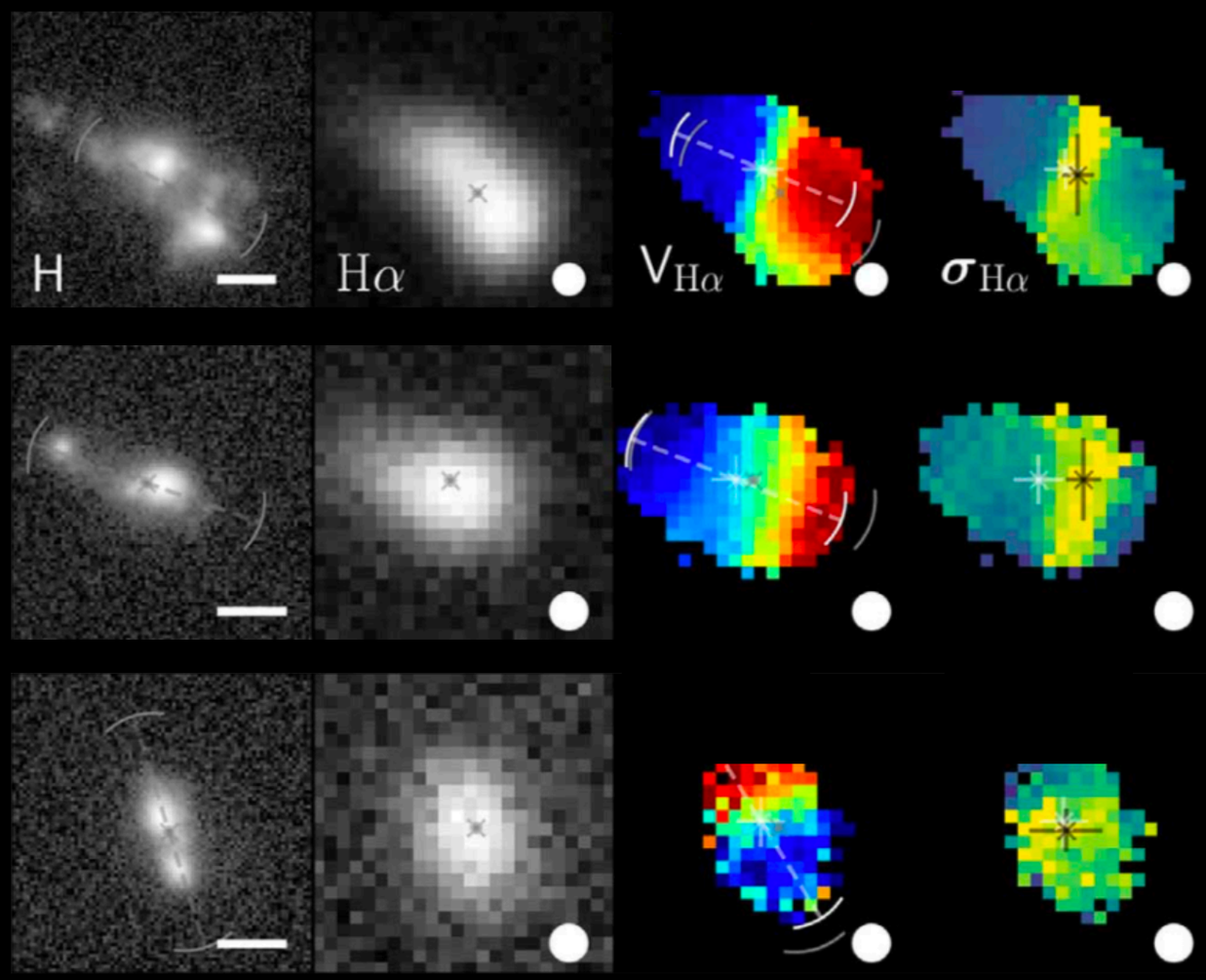
Disk galaxies

as determined from intrinsic kinematic properties

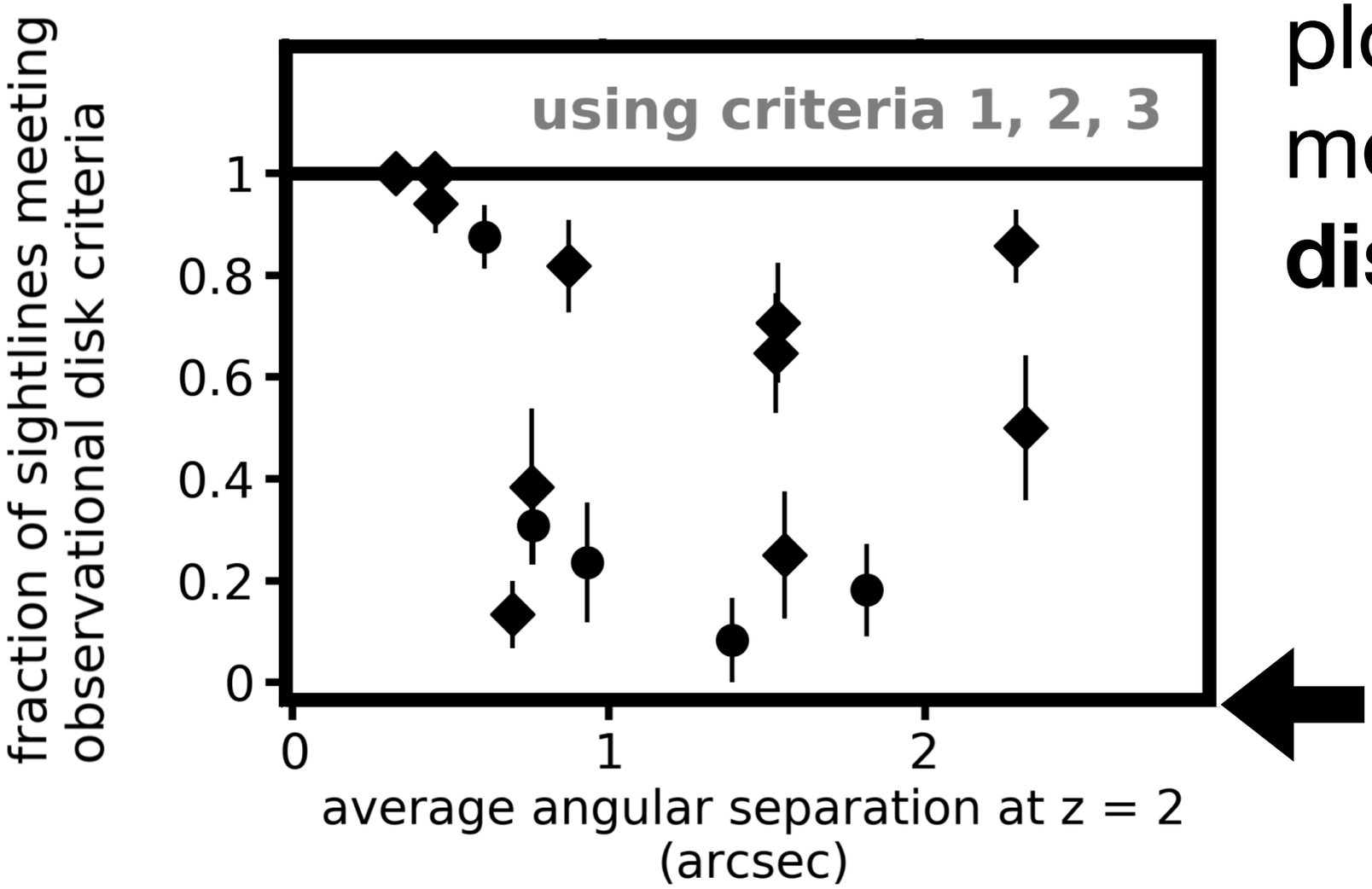
Non-disk mergers

as determined from intrinsic kinematic properties





Simons+ 19



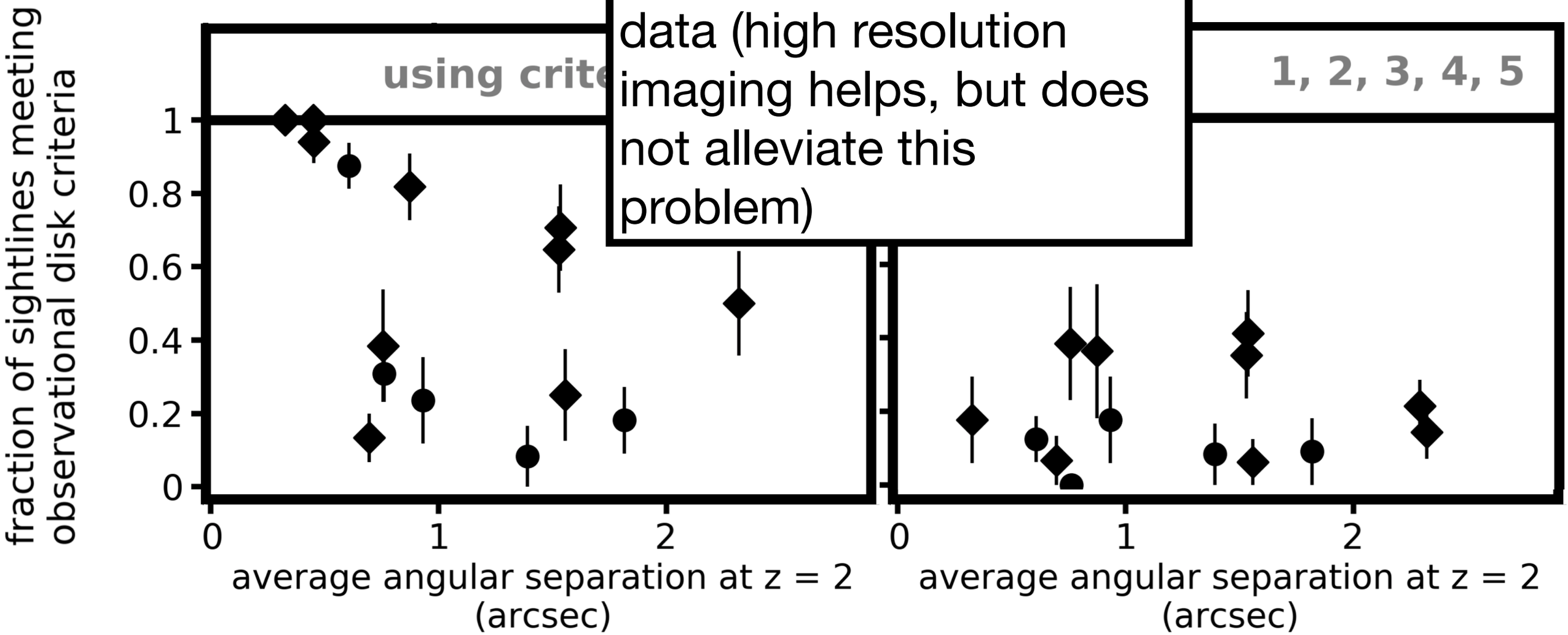
each point on this plot is a simulated merger **without a disk**

ideally, none of the synthetic data would indicate they are disks (i.e., they would lie here)

Simons+ 19

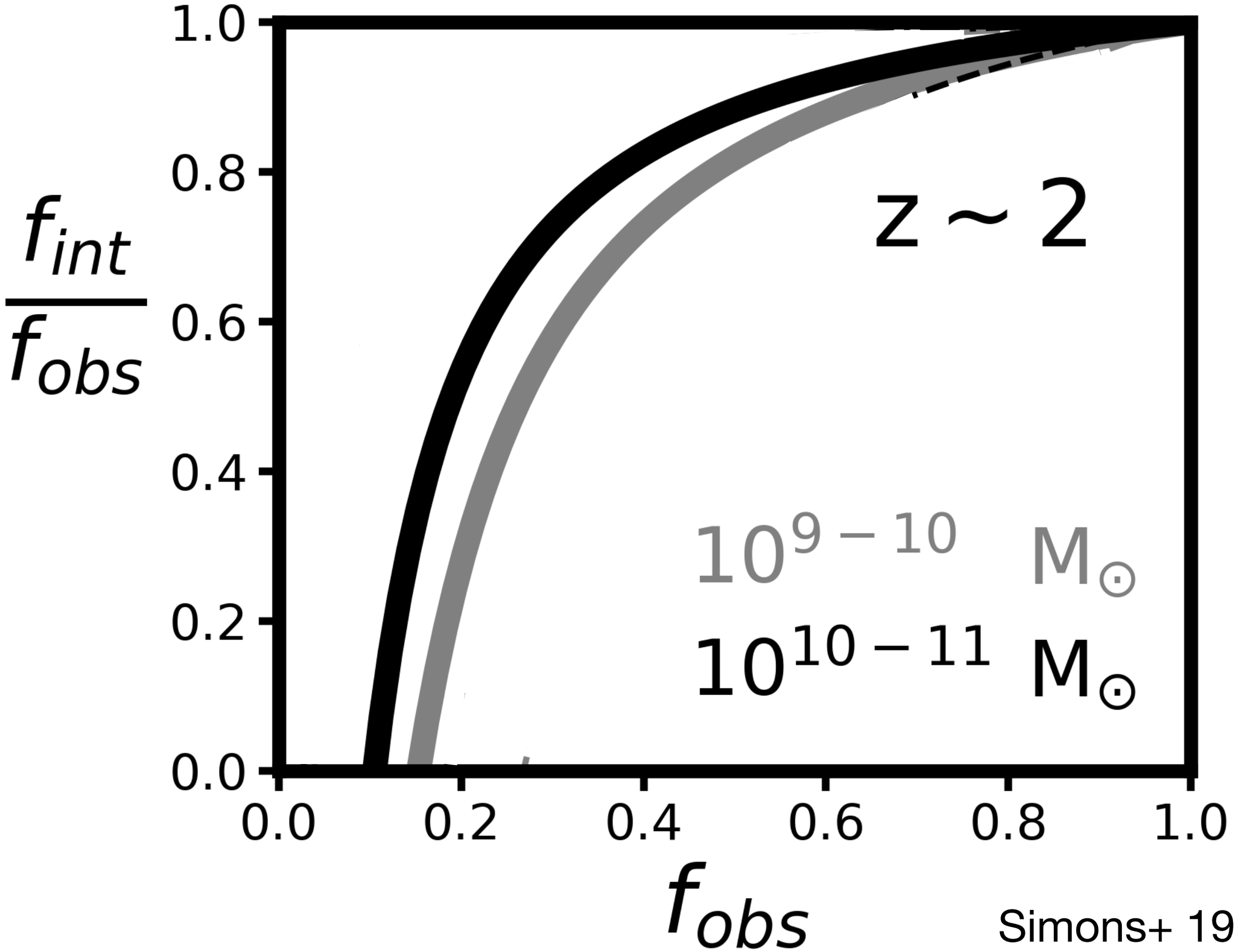
see also e.g., Rodrigues+ 17

Take home: mergers masquerade as disks in low resolution kinematic data (high resolution imaging helps, but does not alleviate this problem)



Simons+ 19

see also e.g., Rodrigues+ 17


$\frac{f_{int}}{f_{obs}}$
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
f_{obs}
z ~ 2
10^{9-10} $M_\odot$
10^{10-11} $M_\odot$
Simons+ 19

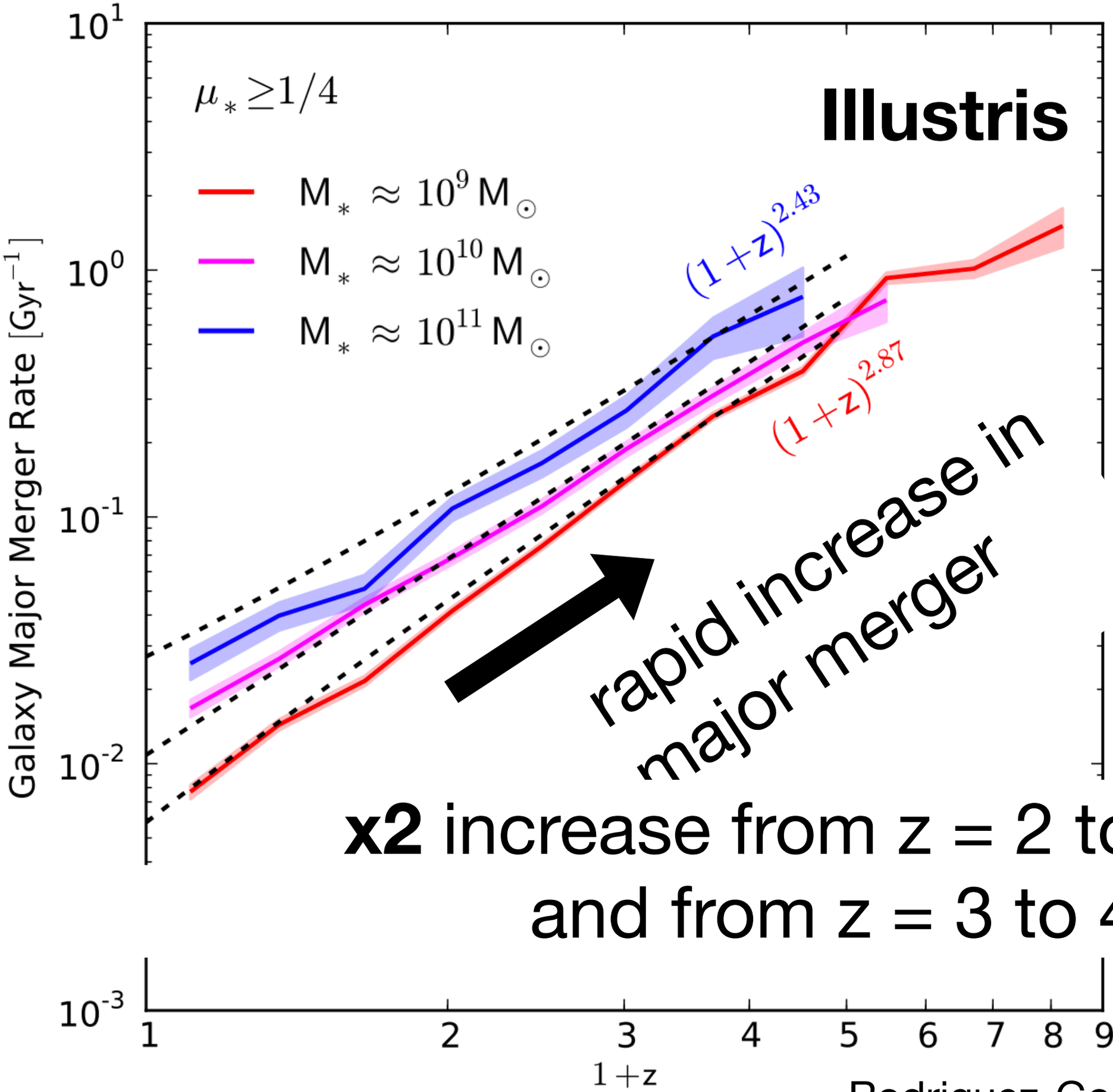
$\frac{f_{int}}{f_{obs}}$

Take home:
observed disk fractions at z~2 need only a small correction (<15%) for contamination by unresolved mergers

observations

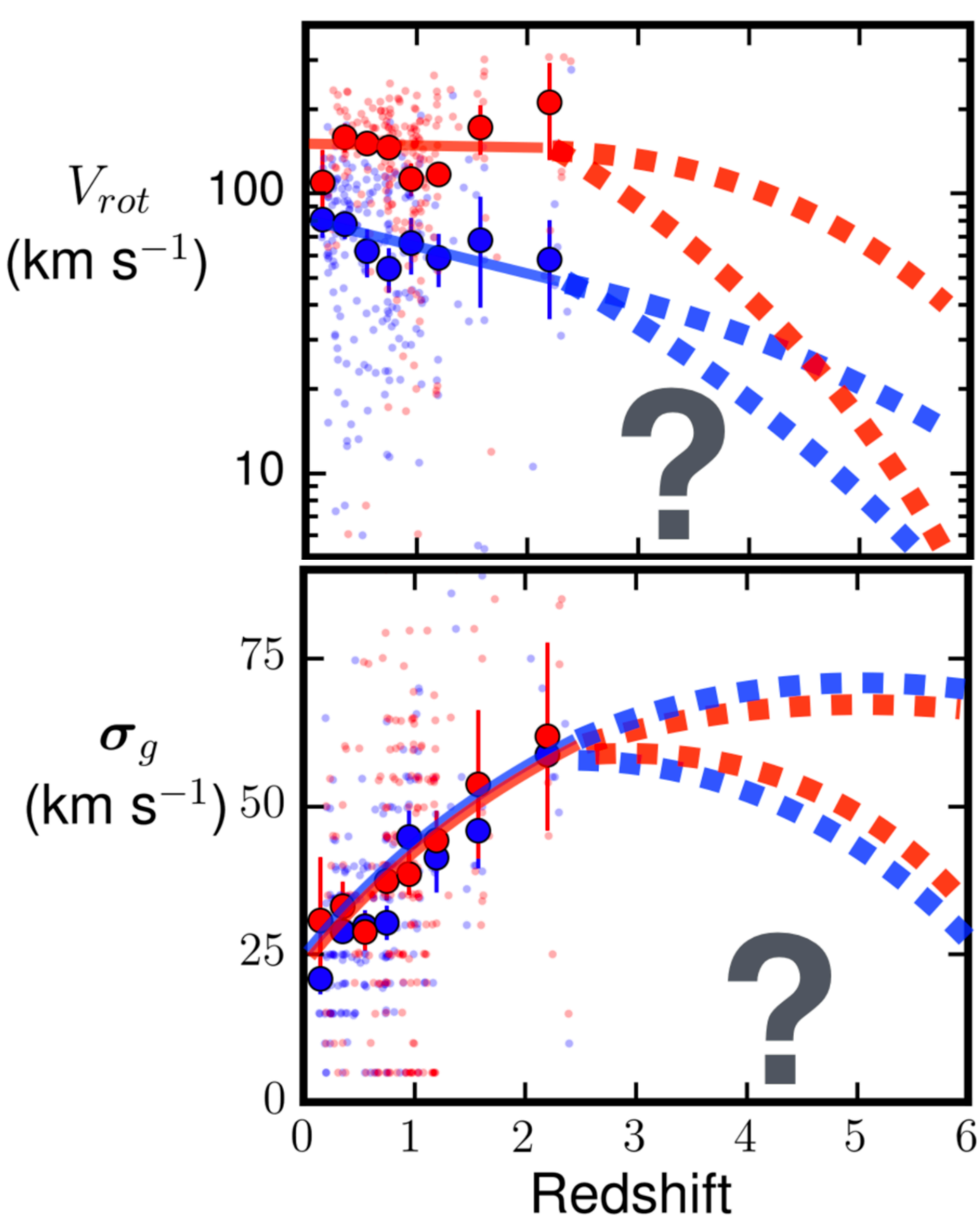
f_{obs}

Simons+ 19



x2 increase from z = 2 to 3
and from z = 3 to 4.5

Rodriguez-Gomez+ 15



The next frontier: resolved gas kinematics to z~6

need resolution offered by 20 - 40 m class facilities

$M_\star/M_\odot = 10^9$ - 10^{10}

$M_\star/M_\odot = 10^{10}$ - 10^{11}

z = 3

gas density

truth

seeing-limited
(0.``6 resolution)

z = 3

gas density

5 kpc

0.``6

truth

10 m AO-assisted
(0.``15 resolution)

z = 3

gas density

5 kpc
0.``6

truth

30 m AO-assisted
(0.``02 resolution)

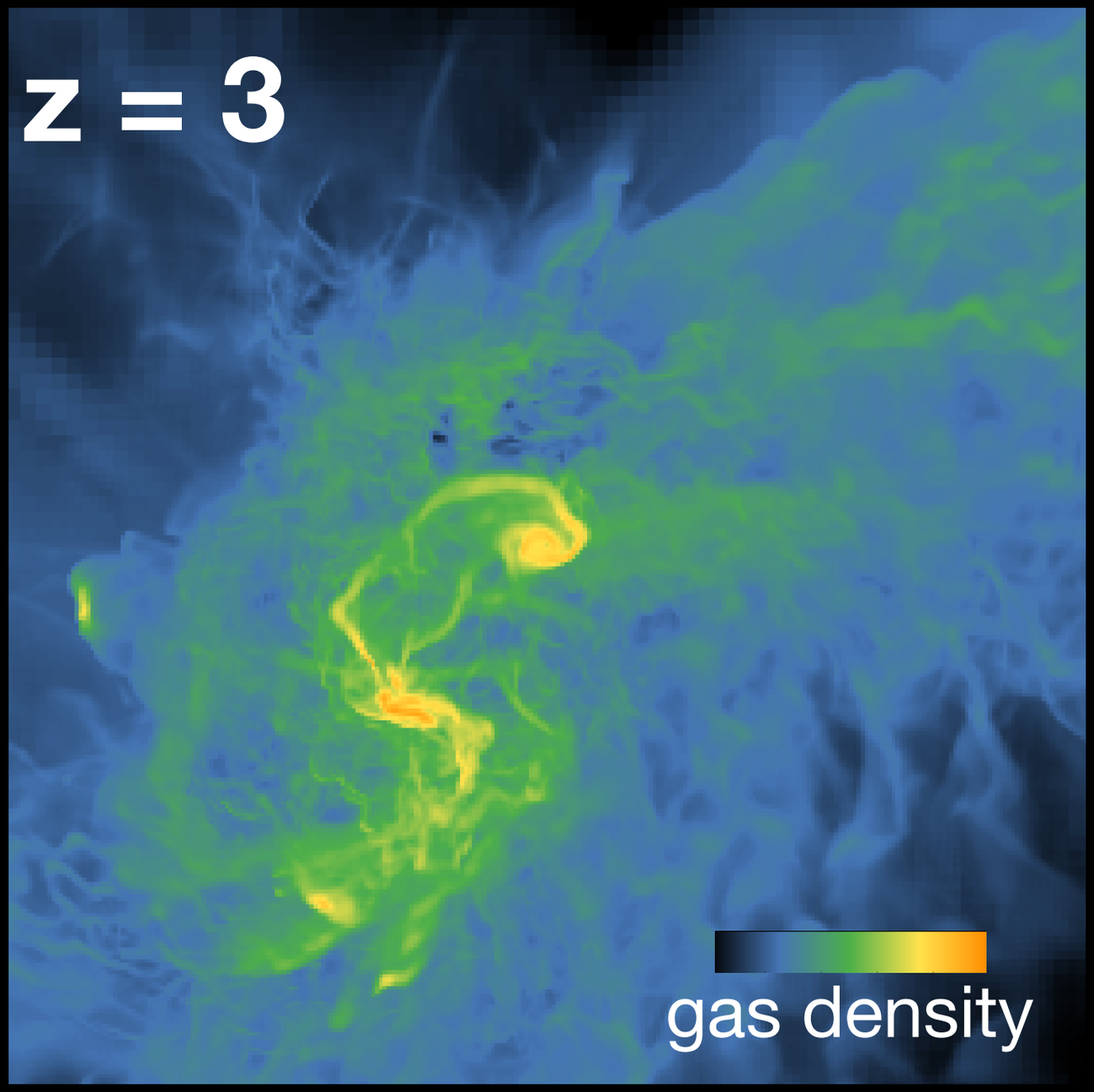
z = 3

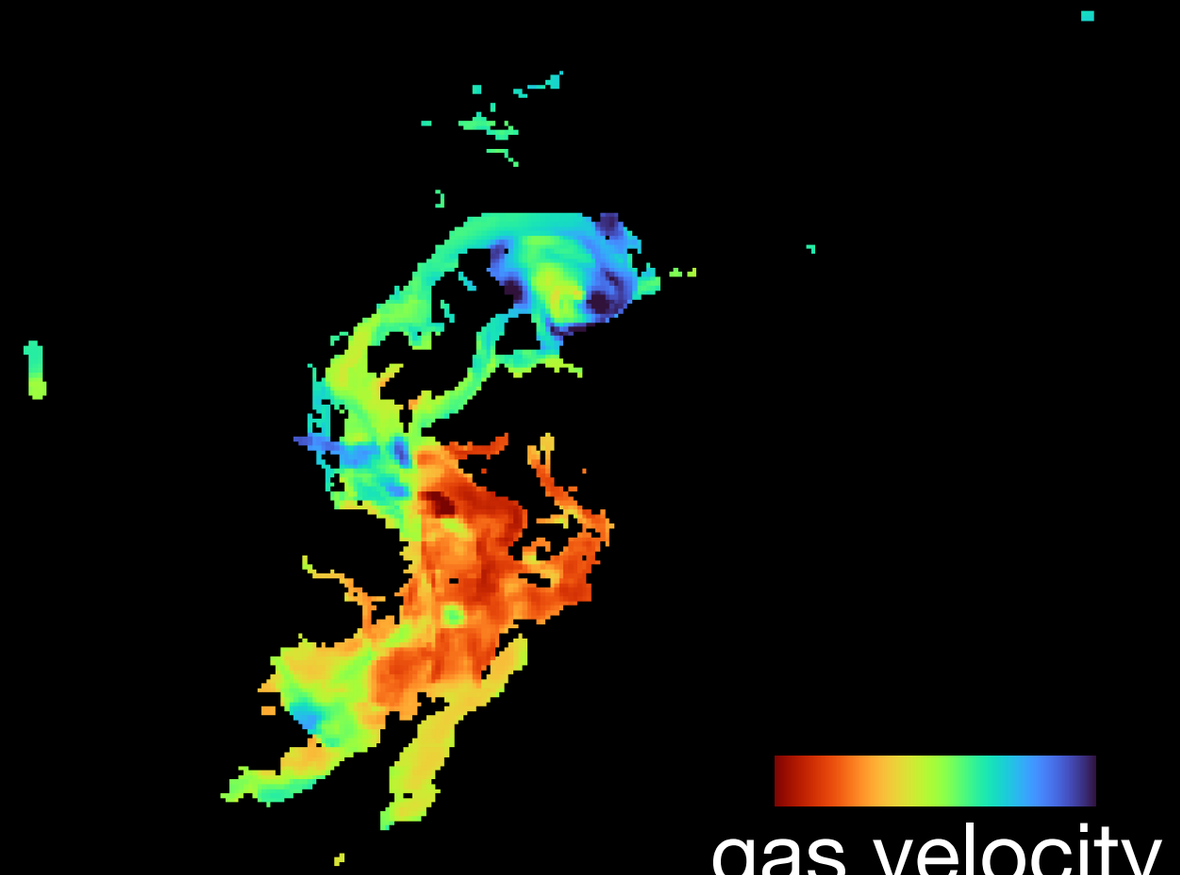
gas density

5 kpc

0.``6

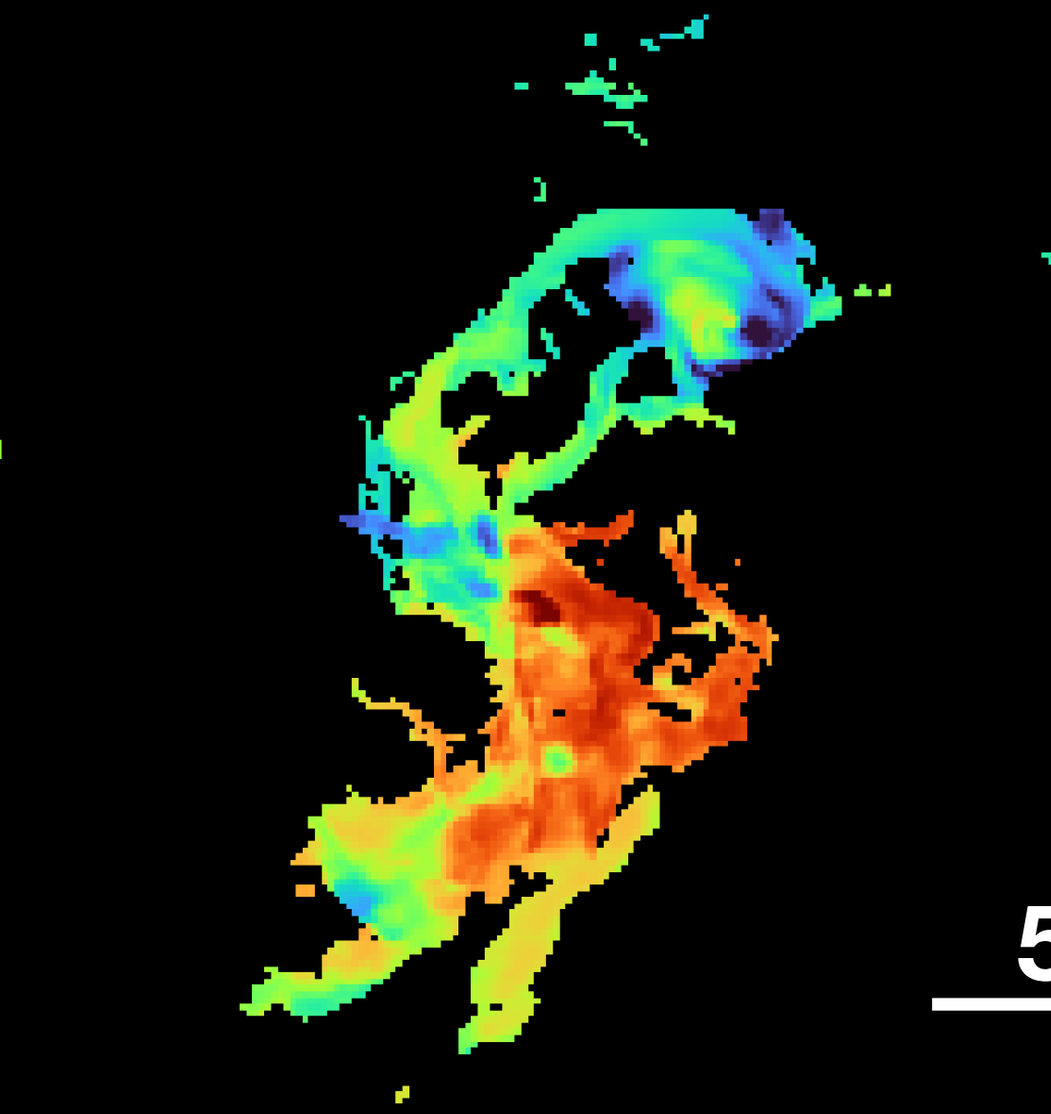
truth





truth

z = 3



5 kpc

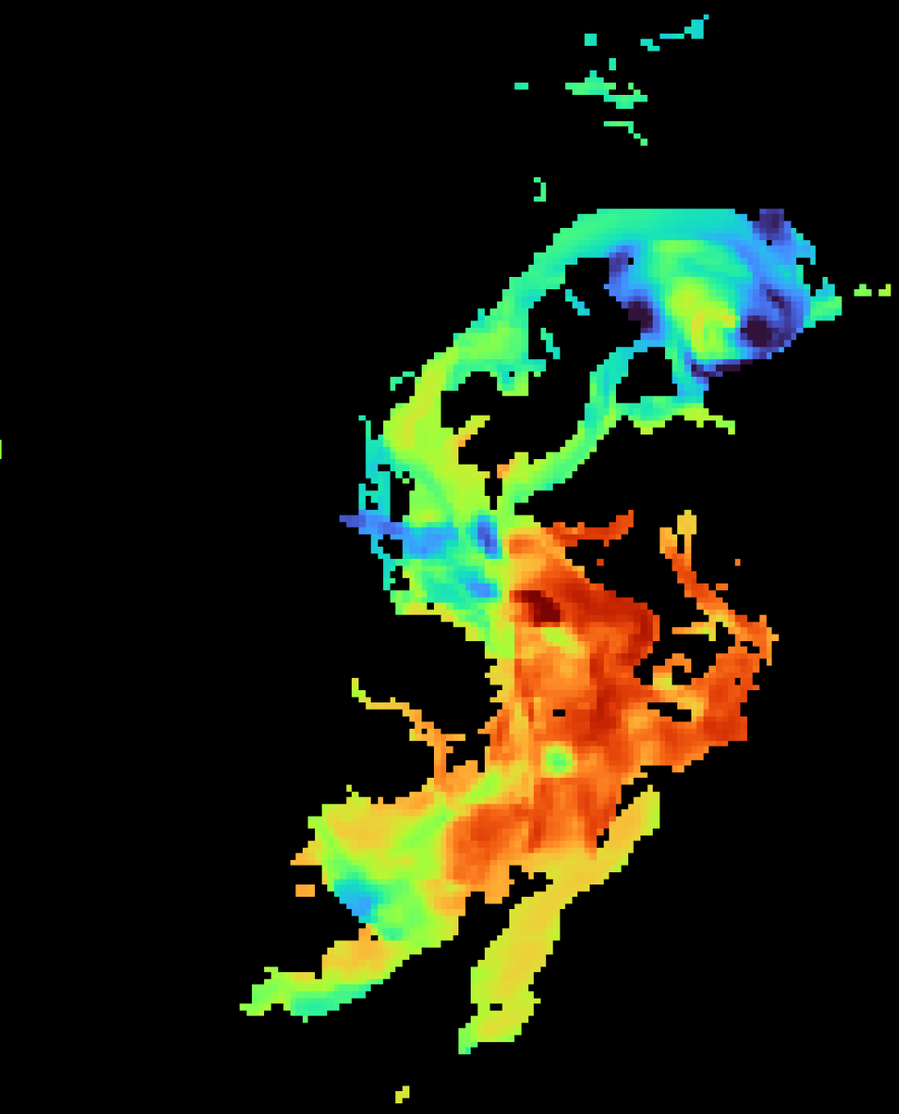
0.``6

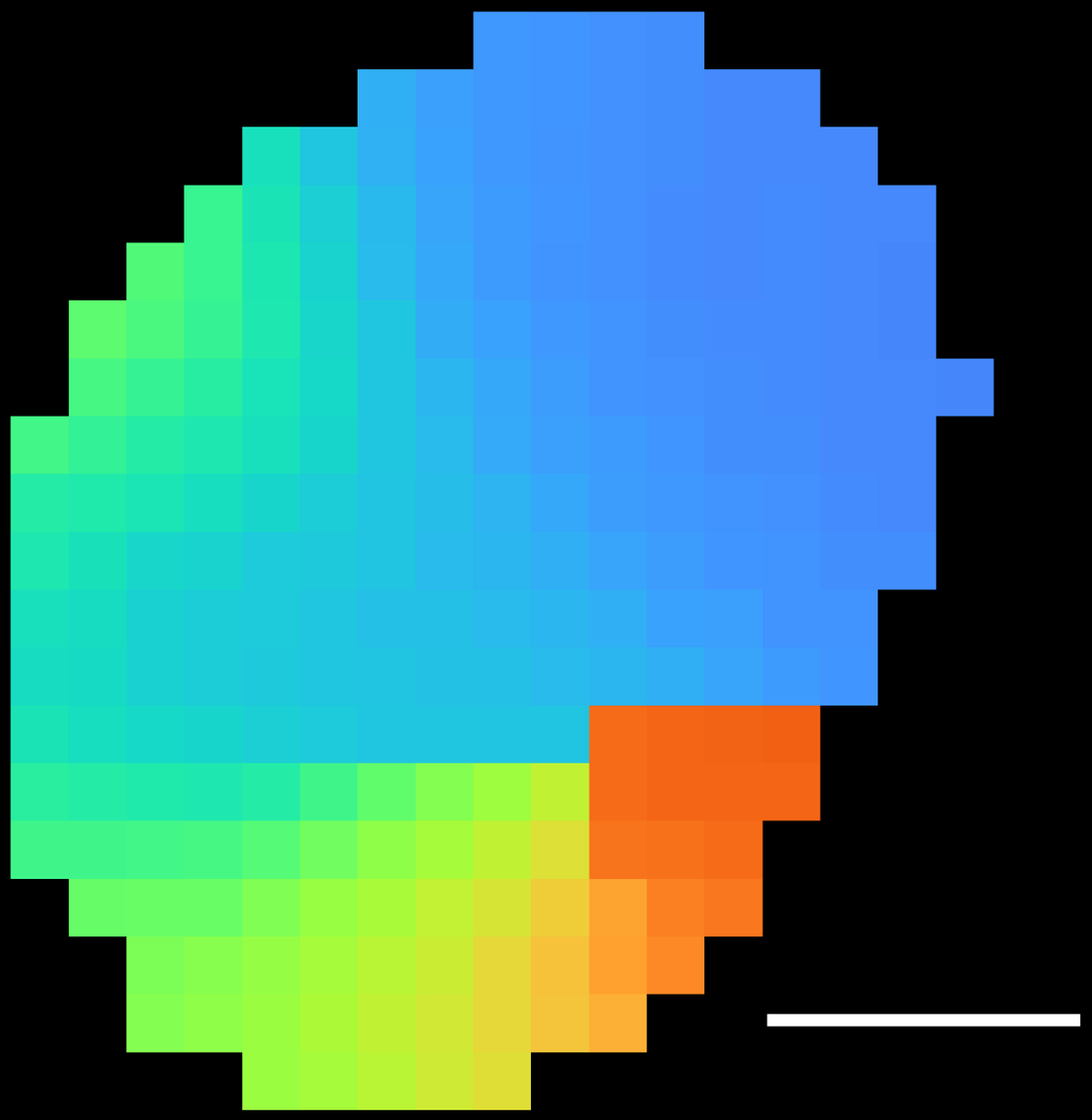
truth

seeing-limited
(0.``6 resolution)

z = 3

gas velocity





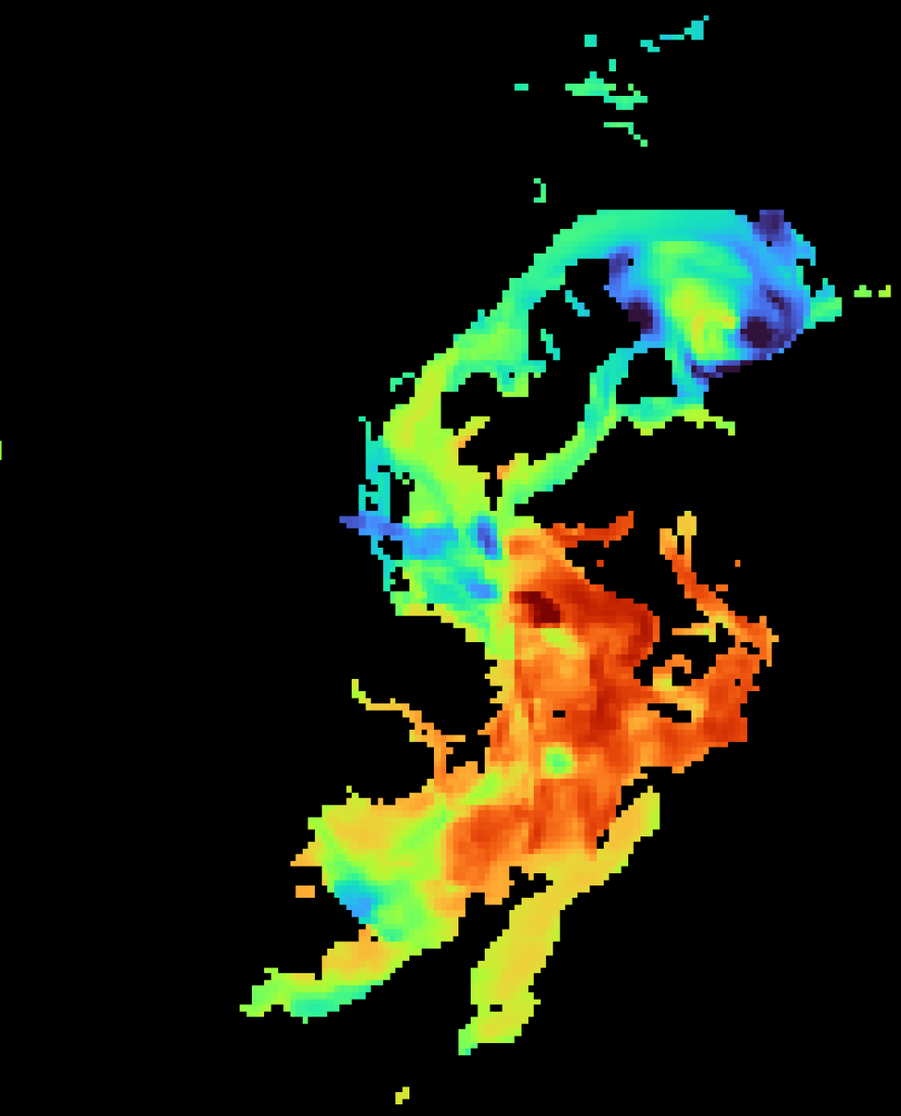
5 kpc
0.``6

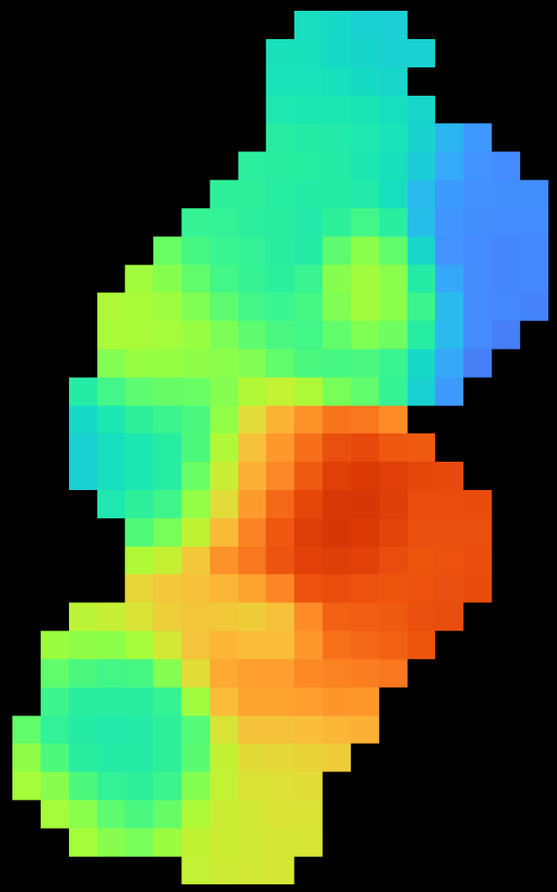
truth

10 m AO-assisted
(0.``15 resolution)

z = 3

gas velocity





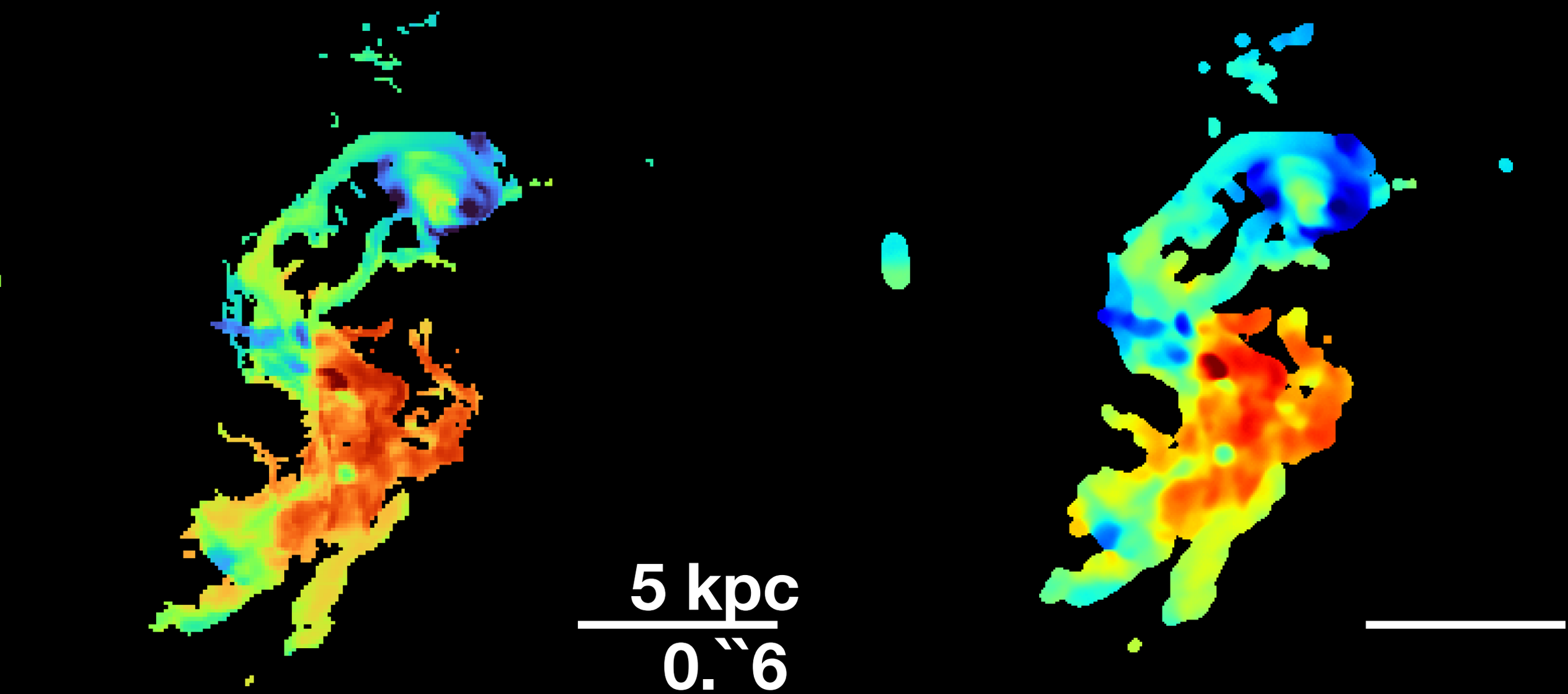
5 kpc
0.``6

truth

30 m AO-assisted
(0.``02 resolution)

z = 3

gas velocity

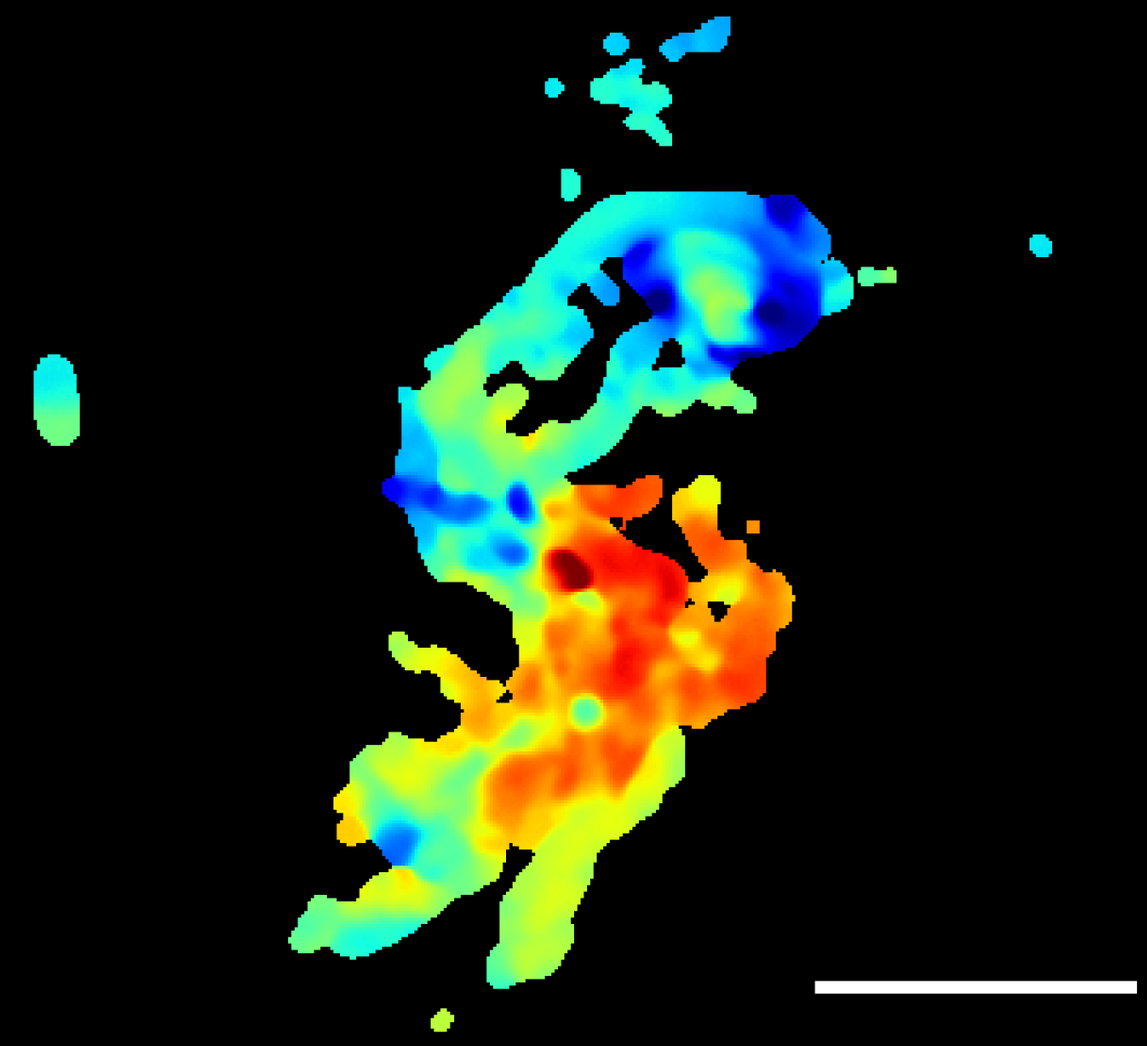


measuring coherence of kinematics (rotational motions, turbulence and winds) to ~100 pc

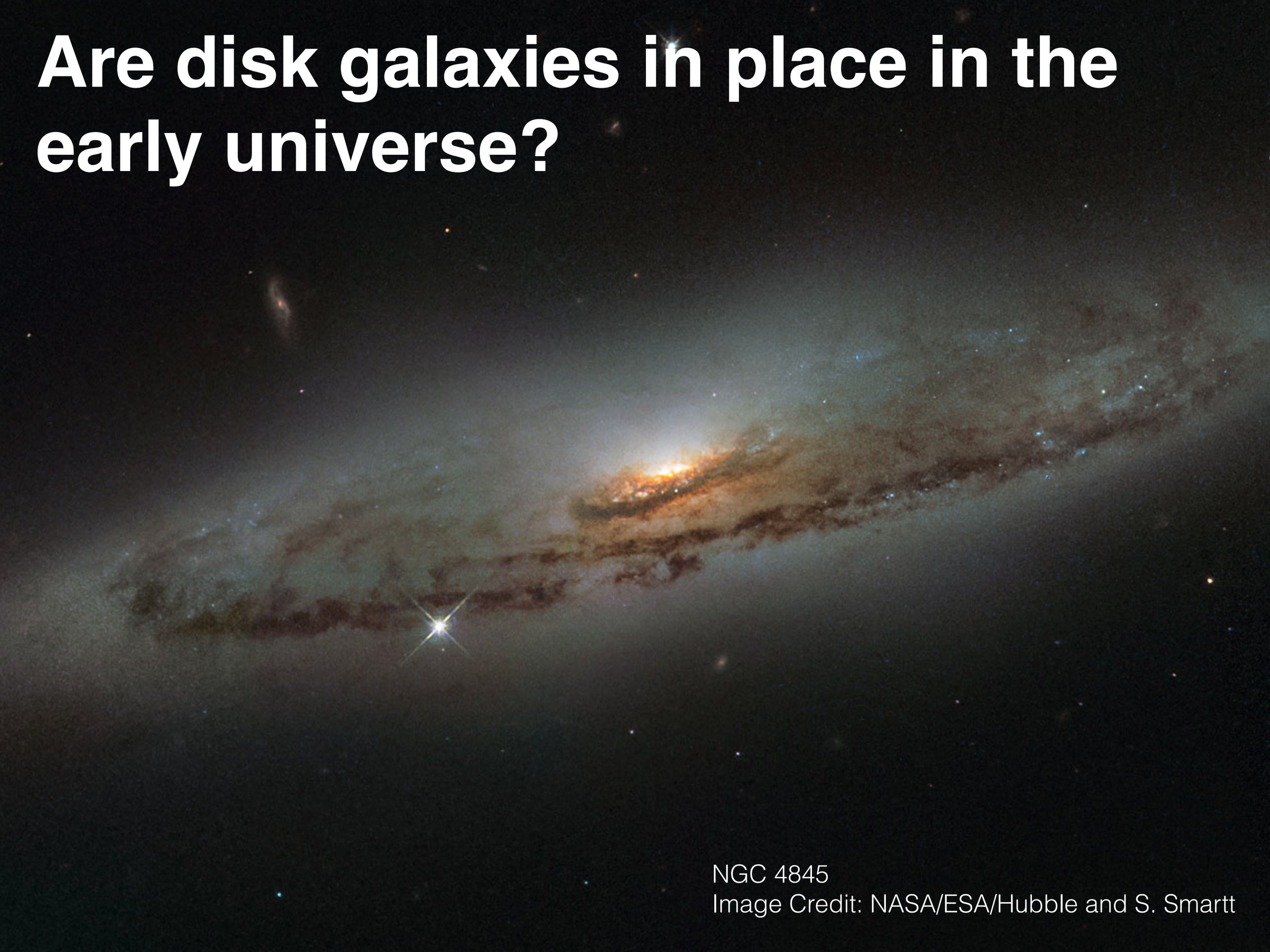
Q for theory: is this small enough to discriminate star-formation feedback models? to discriminate drivers of supersonic turbulence (e.g., gravitational- versus SNe-driven)?

30 m AO-assisted (0.``02 resolution)

gas velocity



Are disk galaxies in place in the early universe?



NGC 4845
Image Credit: NASA/ESA/Hubble and S. Smartt

Are disk galaxies in place in the early universe?

Observations favor a disruptive mode of galaxy formation at early times.

- At z~2, less than one-third of star-forming galaxies have $V_{rot}/\sigma_g > 3$ (i.e., strong rotational support)

Synthetic observations of simulations indicate:

- merging galaxies masquerade as disks in low-resolution kinematic data
- high merger rates at z > 3 necessitate resolution of extremely large telescopes — along with a direct bridge to theoretical predictions (through synthetic observations) to reliably interpret data and test physical models