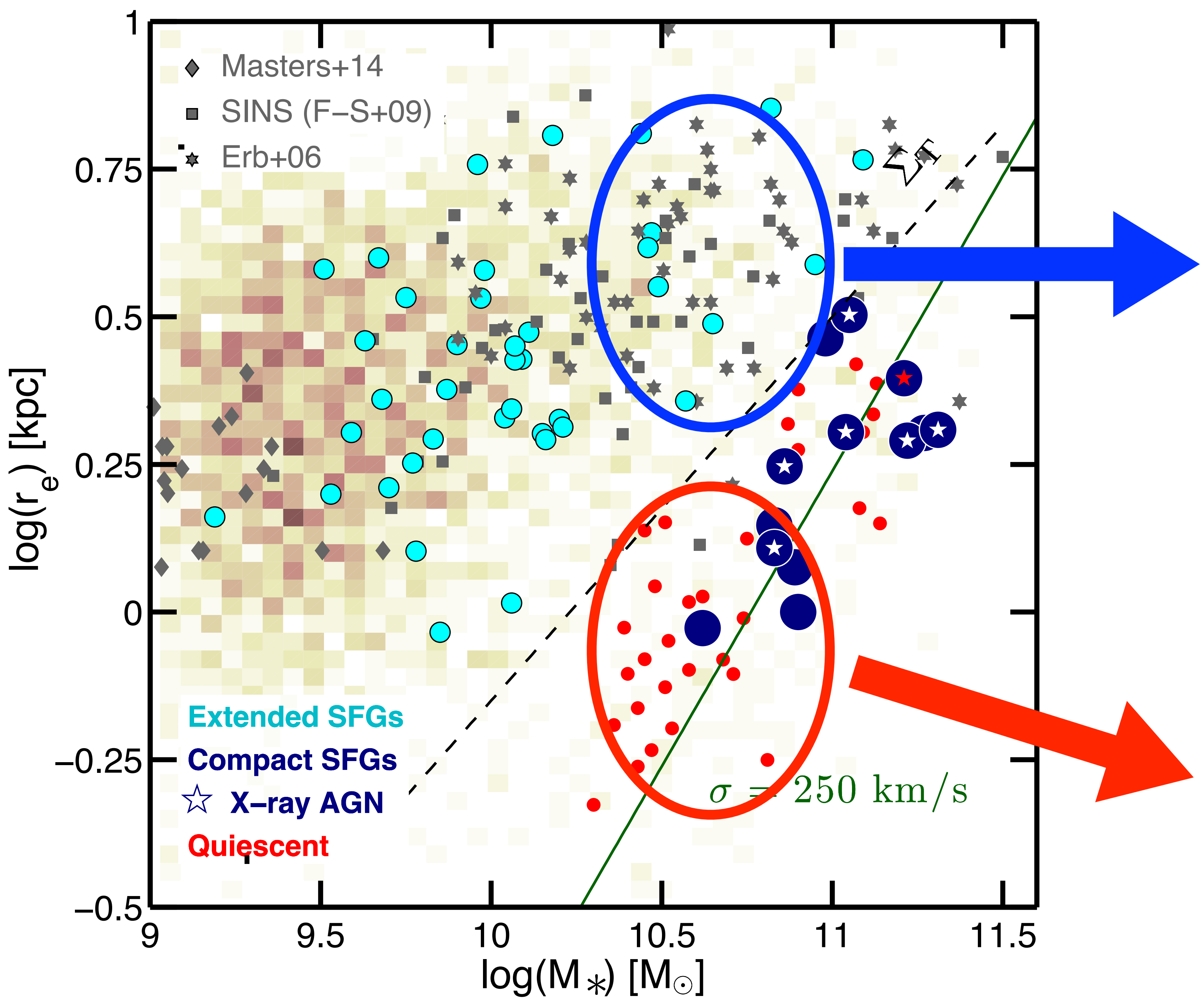
Review of recent studies for galaxies at z=1-3

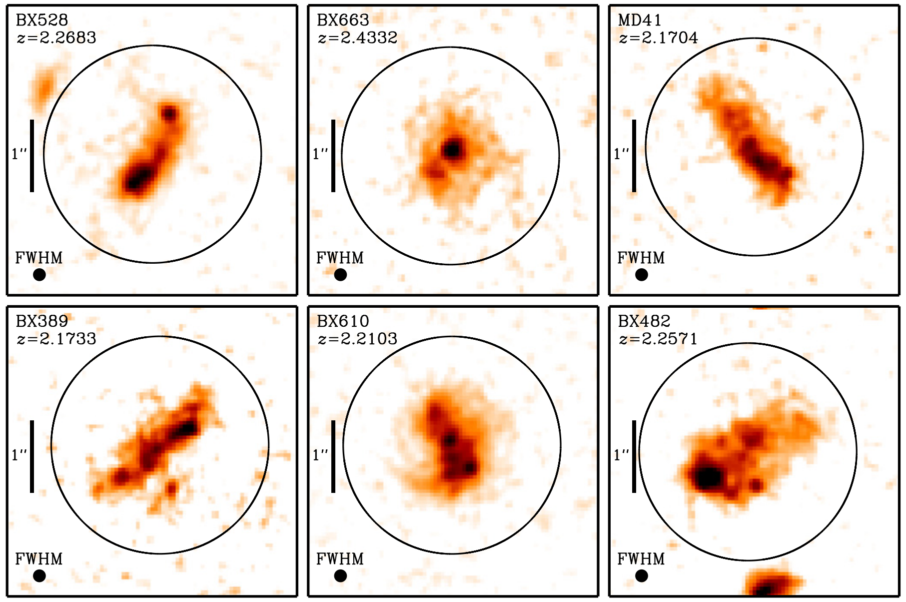
Ken-ichi Tadaki (NAOJ)

Extended clumpy disks and nuggets

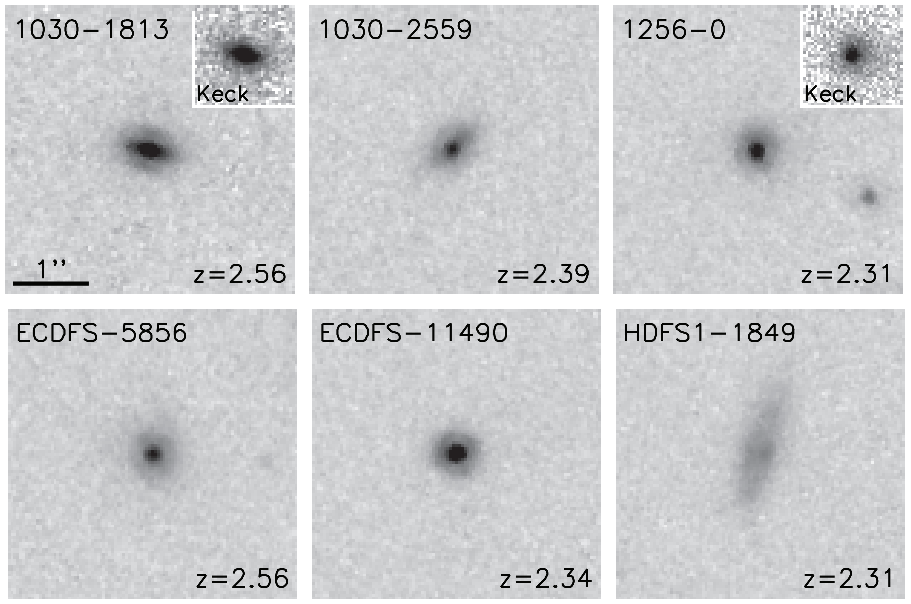
galaxies at $2<z_{phot}<3$ in GOODS-S field



extended clumpy disks

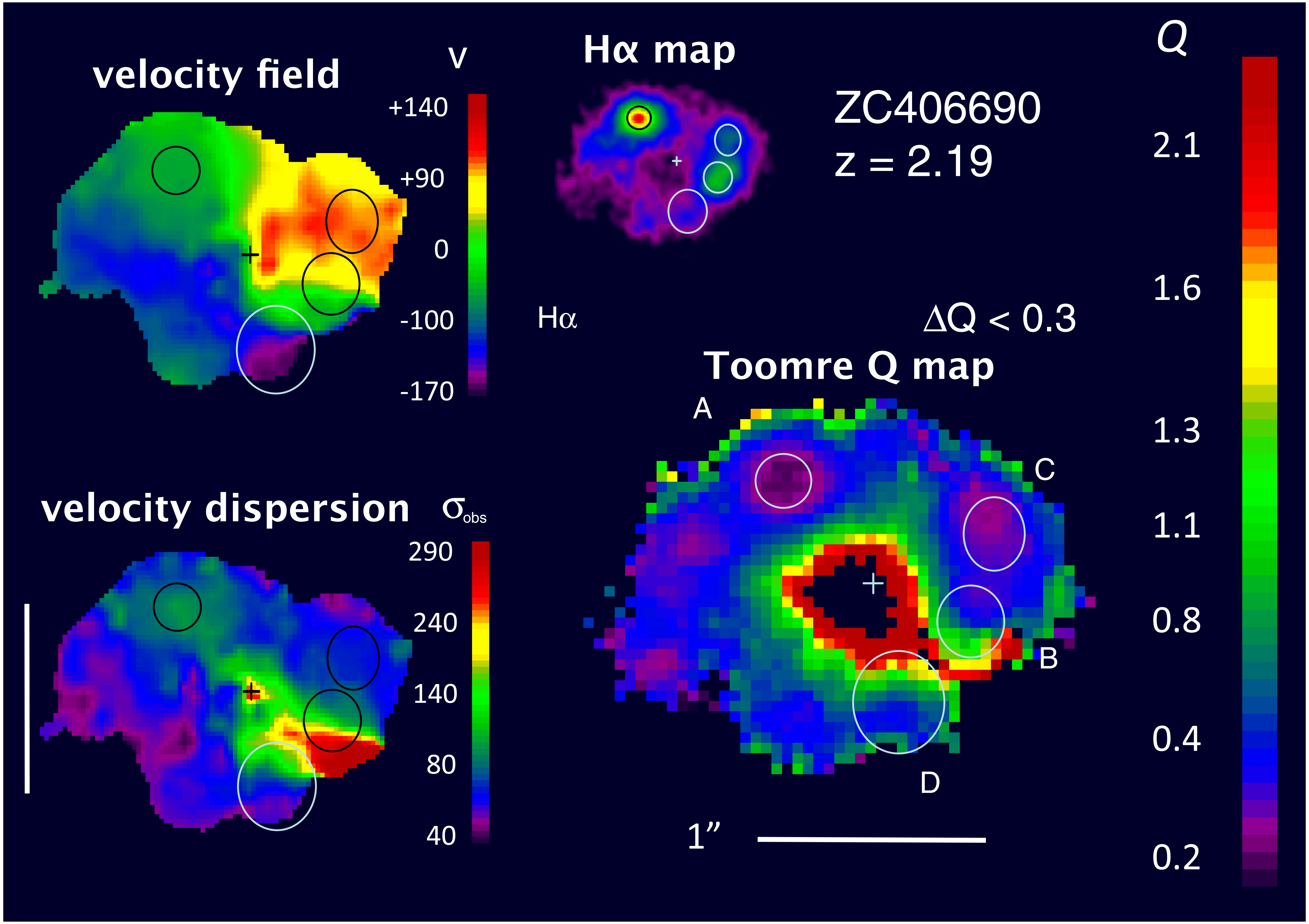


blue/red nuggets



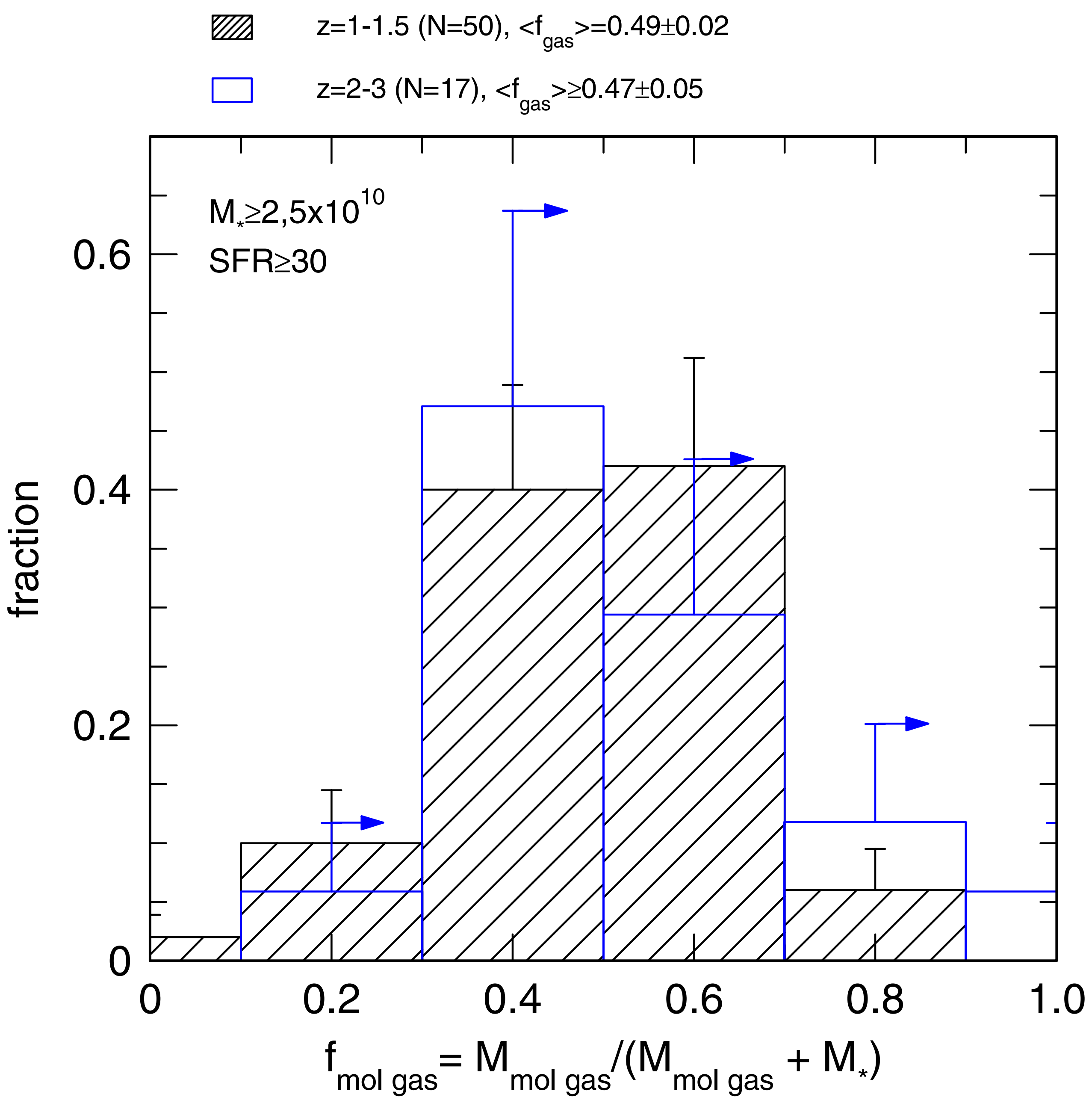
Barro+14, Forster Schreiber+11, van Dokkum+08

Results from IFU studies of high-redshift SFGs

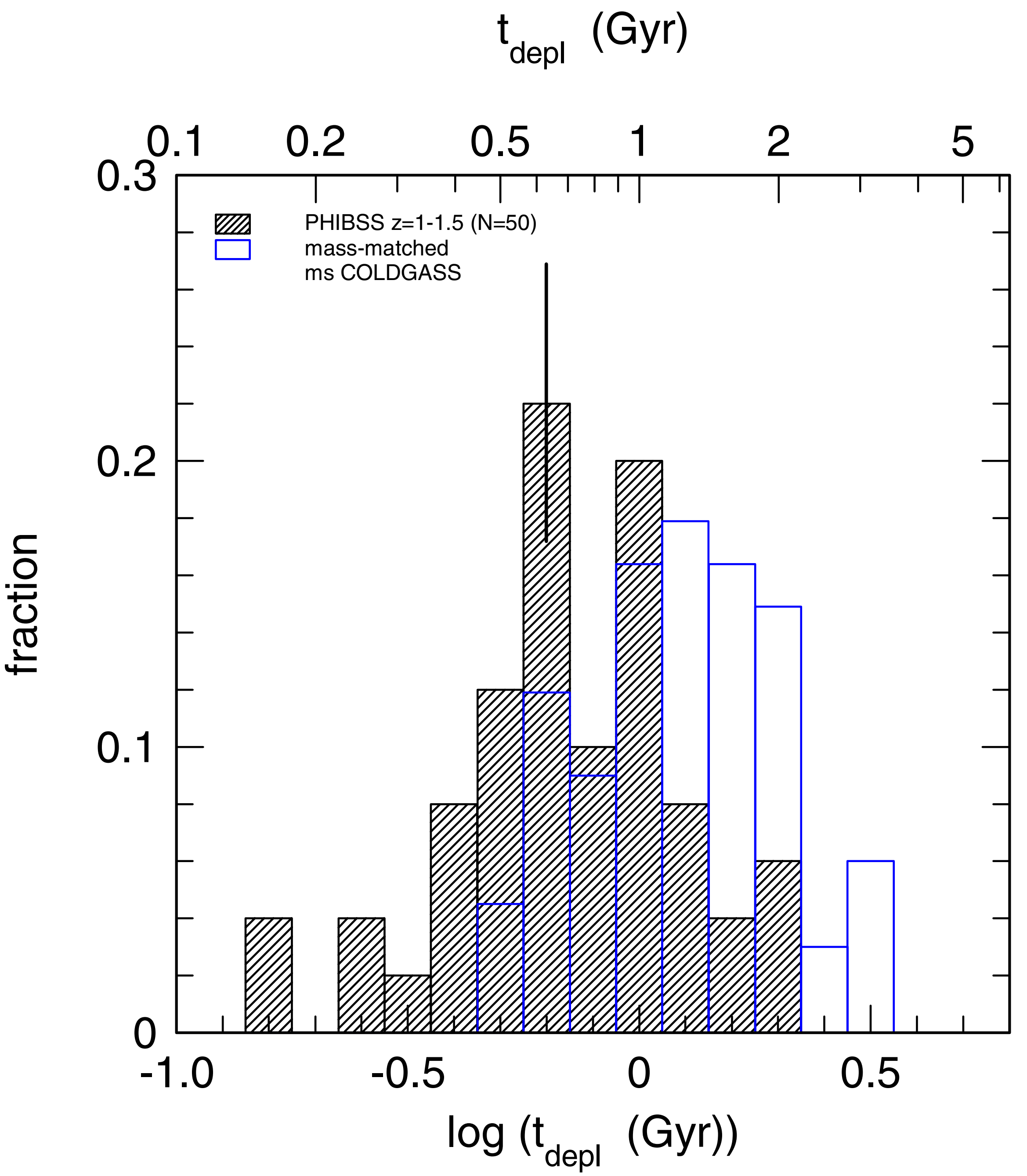


Genzel+11

Results from CO studies of high-redshift SFGs



gas fraction ~ 50%

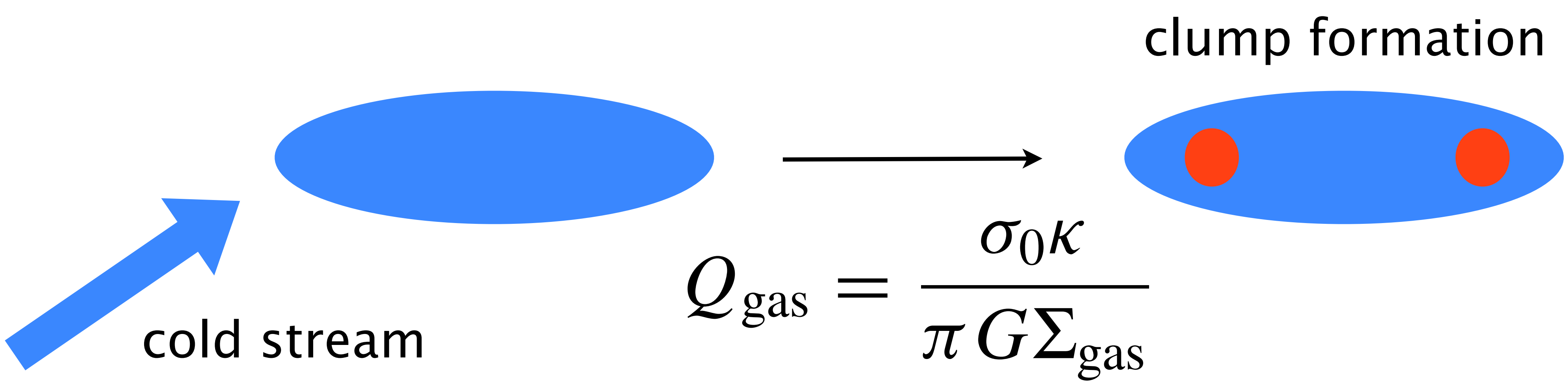


gas depletion timescale ~ 700Myr

Tacconi+13

Differences between high-z and low-z galaxies

	high-z	low-z
SFR	~ 100 M_{sun}/yr	<10 M_{sun}/yr
gas fraction	40-50 %	10%
gas depletion time-scale	~700 Myr	1-2 Gyr
morphology	clumpy disk	spiral disk
velocity dispersion	~50 km/s	~10 km/s



$$Q_{\rm gas} = \frac{\sigma_0 \kappa}{\pi G \Sigma_{\rm gas}}$$

Differences between high-z and low-z galaxies

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gas fraction	40-50 %	10%
gas depletion time-scale	~700 Myr	1-2 Gyr
morphology	clumpy disk	spiral disk
velocity dispersion	**~50 km/s**	**~10 km/s**

the main driver of large velocity dispersion is not well understood

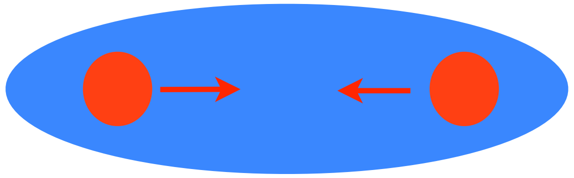
1. stellar feedback (outflow)
2. **self-regulating disk (inflow within disk)**

Self-regulated disks

if $\sigma < \sigma_r$ (Q<1)

release of gravitational energy

$$\dot{M}_{\rm inflow} V_{\rm circ}^2 \simeq \frac{M_{\rm gas}\sigma_{\rm gas}^2}{t_{\rm dis}}$$



$$t_{\rm enc} \simeq 2.1\,\alpha^{-1}\,Q^4\,t_{\rm d}$$

$\sigma_{\rm gas}$ increases

fragmentation becomes more efficient
gravitational interaction drive mass inflow to center
(e.g. clump migration)

if $\sigma > \sigma_r$ (Q>1)

turbulence decay

$$t_{\rm dis} \simeq 1.4\,Q^{-1}\,t_{\rm d}$$

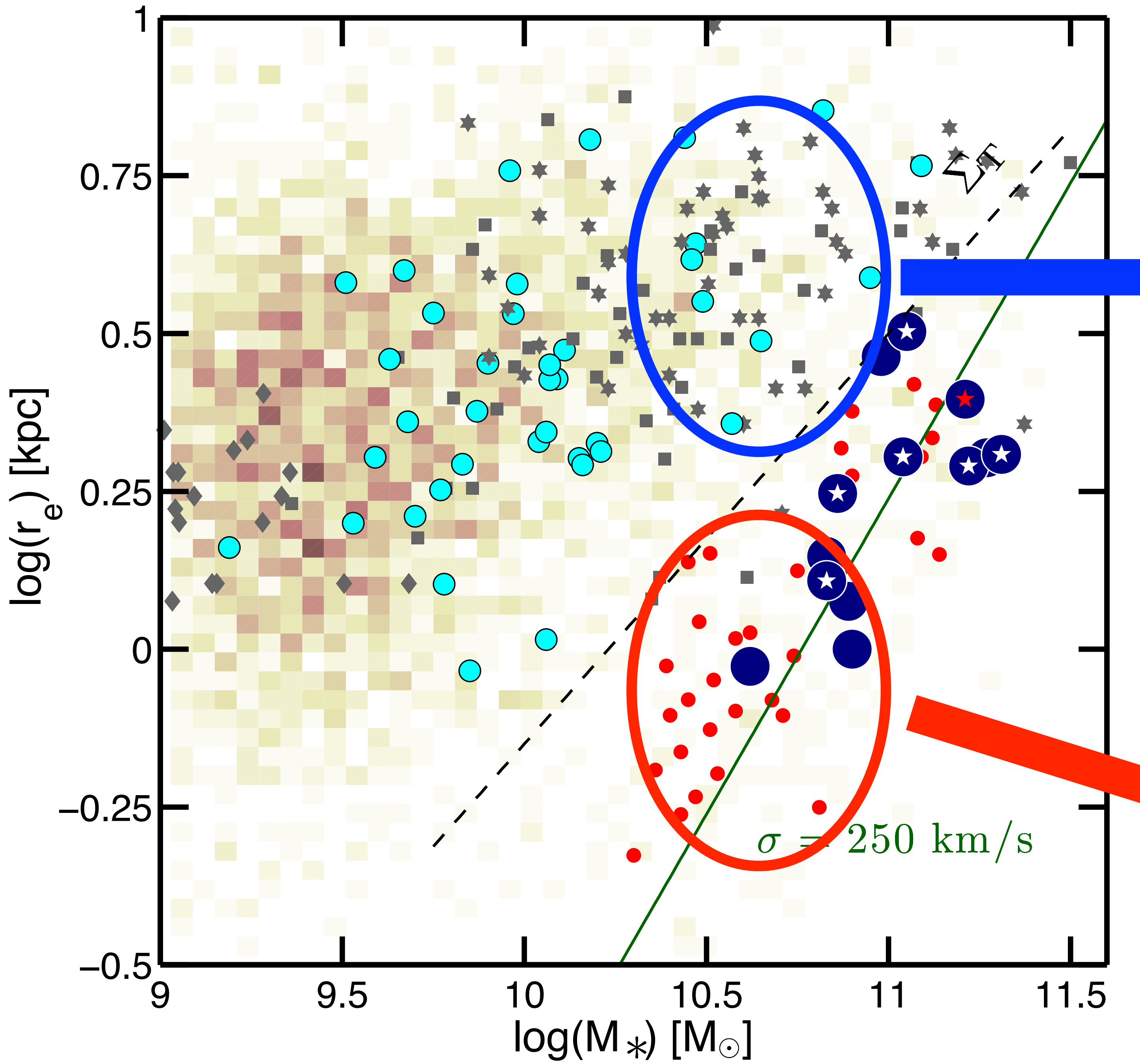
$\sigma_{\rm gas}$ decreases

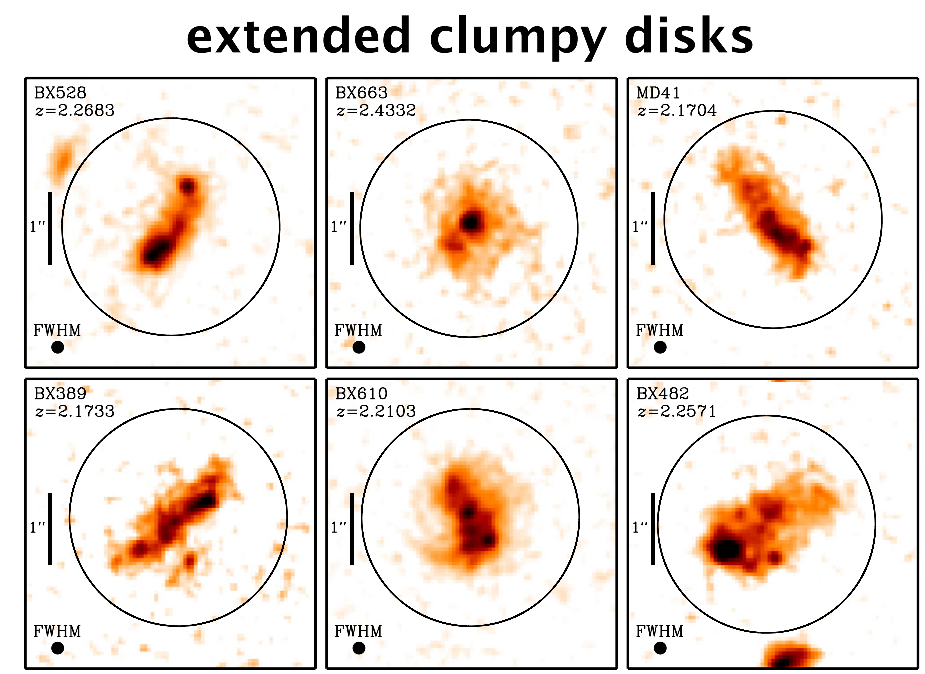
fragmentation process is suppressed

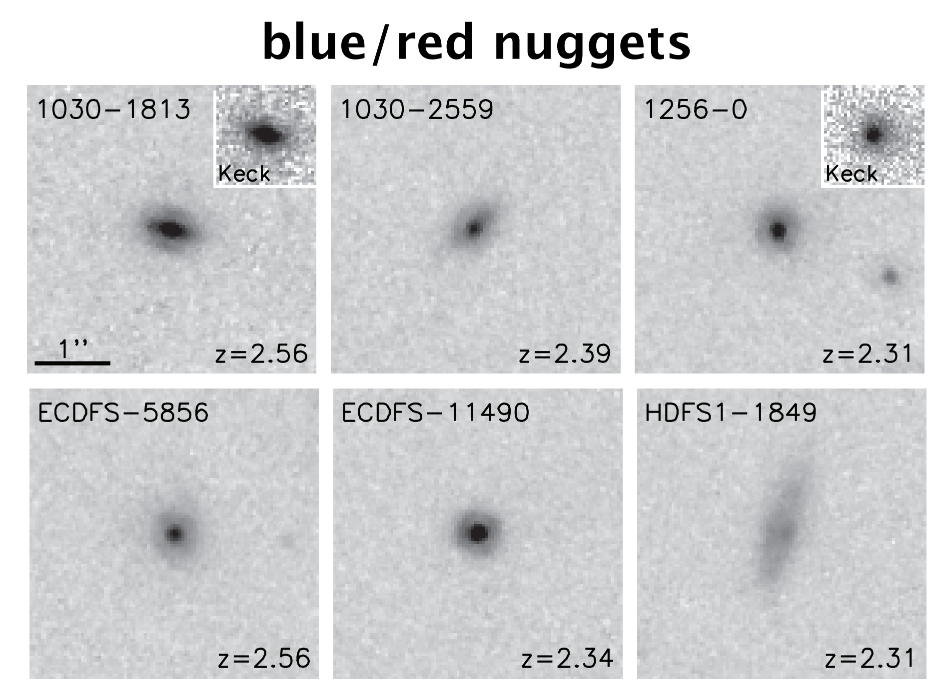
high-redshift galaxies keep a disk unstable (Q~1)

Dekel+09

Blue/red nuggets





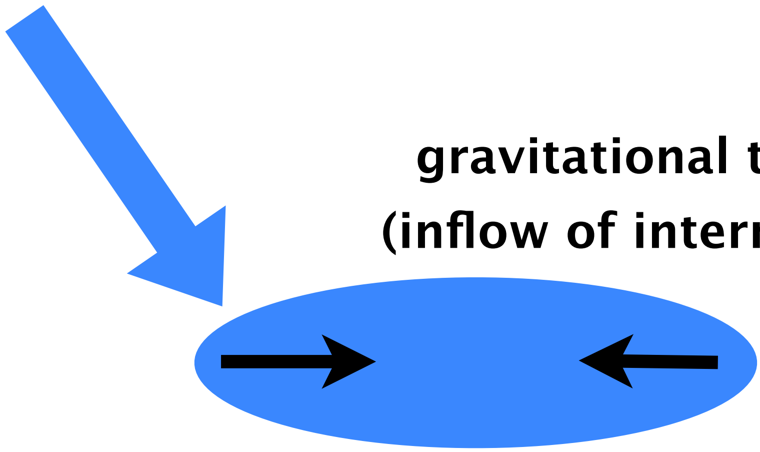


Barro+14, Forster Schreiber+11, van Dokkum+08

Blue/red nuggets

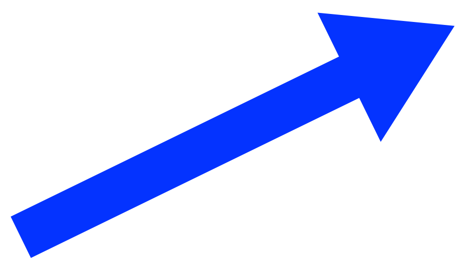
cold stream
(inflow of external gas)

gravitational torque
(inflow of internal gas)



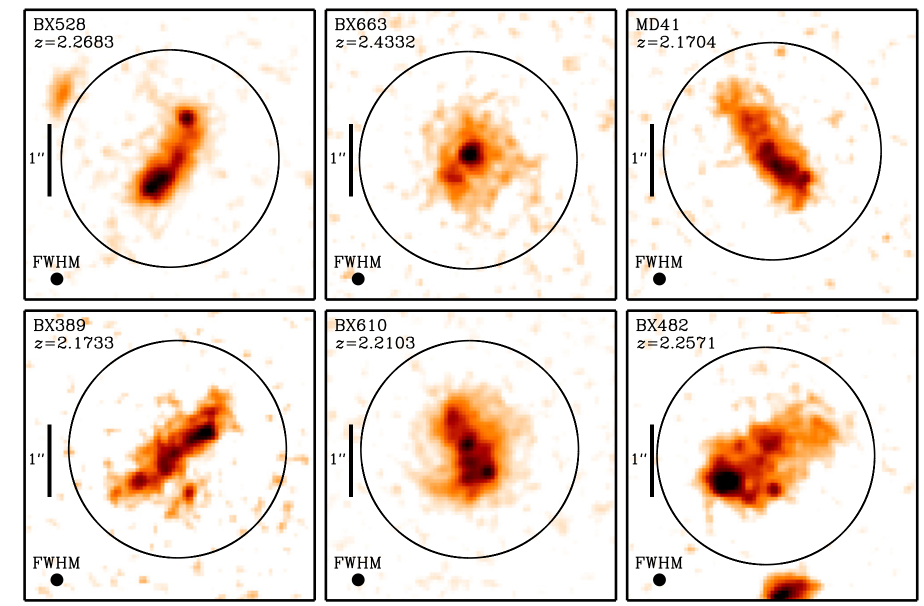
angular momentum of external gas
-> extended disk

if $\tau_{infall} > \tau_{SF}$



self-regulated!

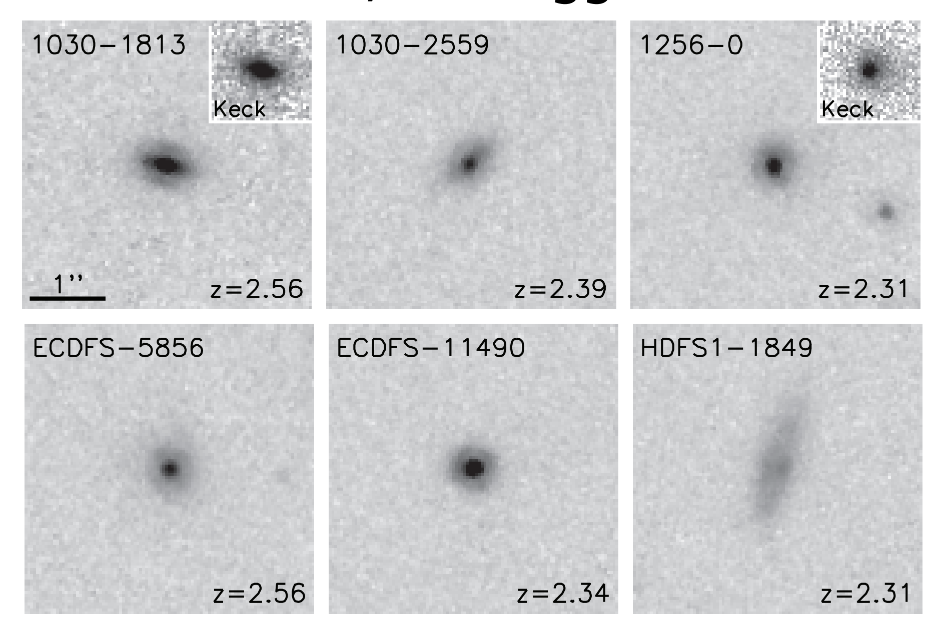
extended clumpy disks



loss of energy/angular momentum
(impossible in stellar systems)
-> gas contraction (nugget)
a necessary condition is $M_{cold}/M_{total} > 0.28$

if $\tau_{infall} < \tau_{SF}$

blue/red nuggets

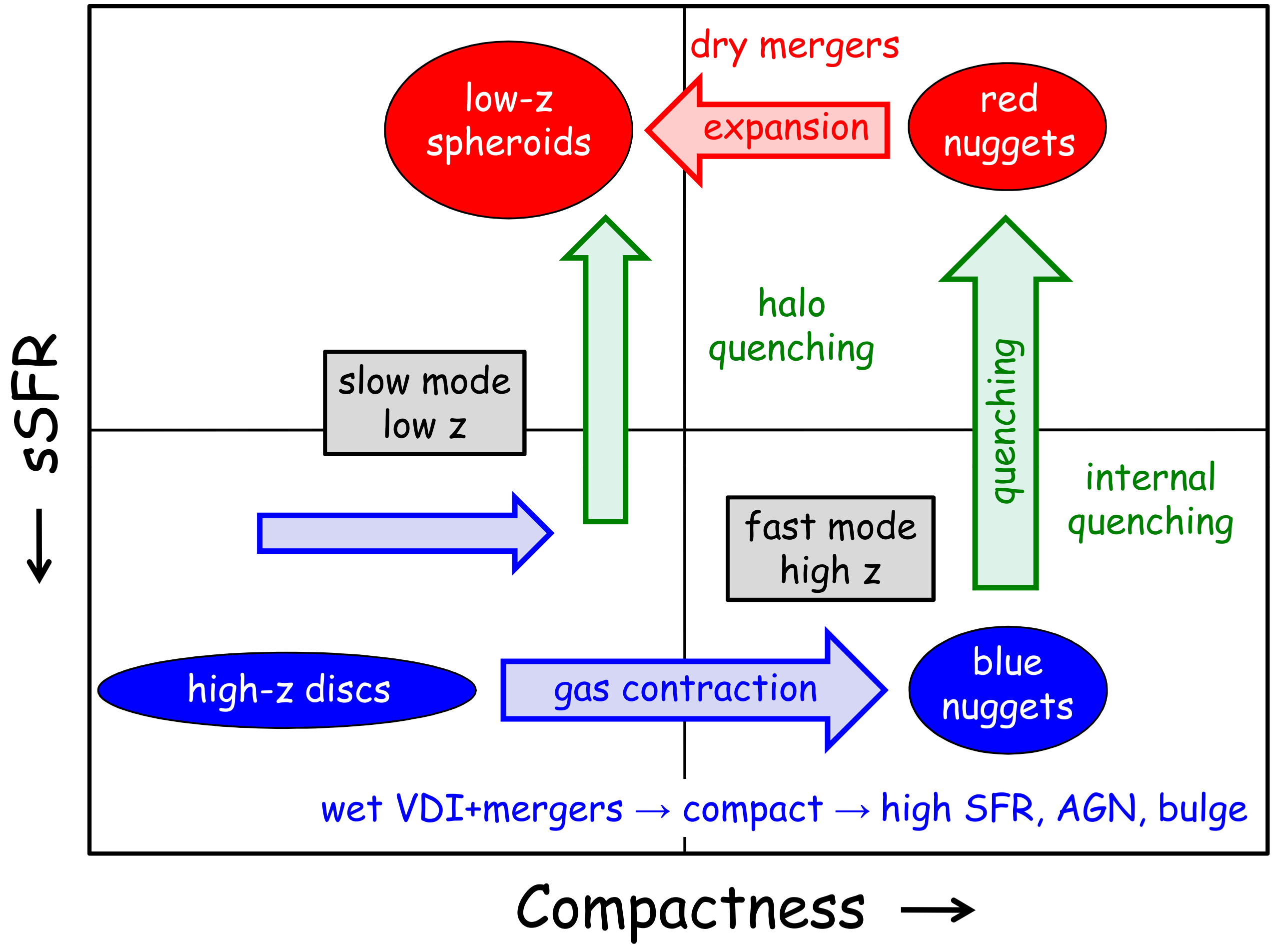


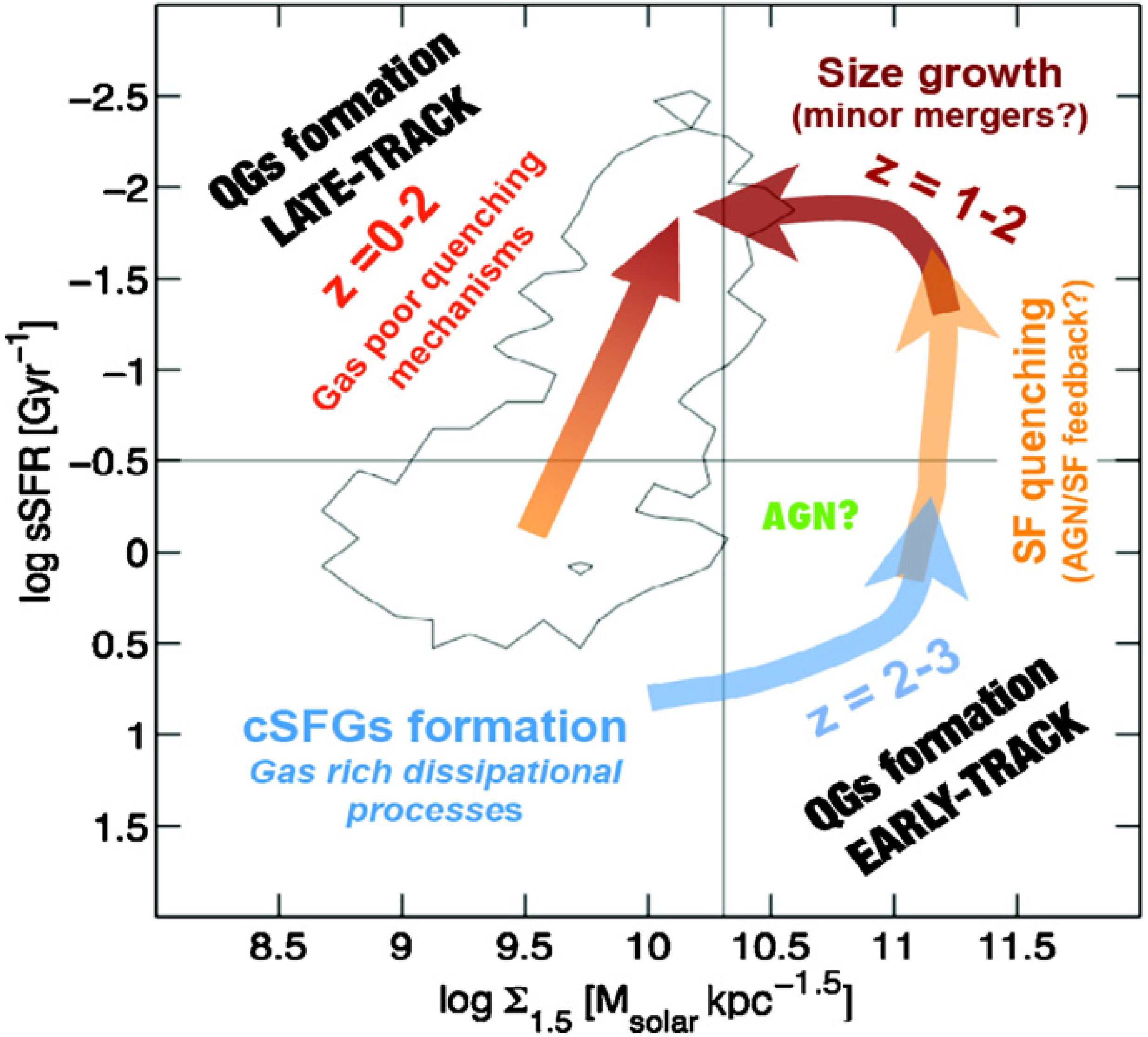
depends on gas fraction!

a theoretical study predicts that about 50% of high-z SFGs are expected to contract to blue nuggets

Dekel+14

Two evolutionary paths for QGs





1. fast/early-track: extended clumpy disks → blue/red nuggets → massive QGs
2. slow/late-track: extended clumpy disks → massive disks → massive QGs

Dekel+14, Barro+13

Next agenda

2003-2013 **sample number**

Observations with SINFONI, IRAM-PdBI, HST/WFC3 revealed the detailed properties of high-z galaxies and predicted the formation scenarios of massive galaxies — **50-100**

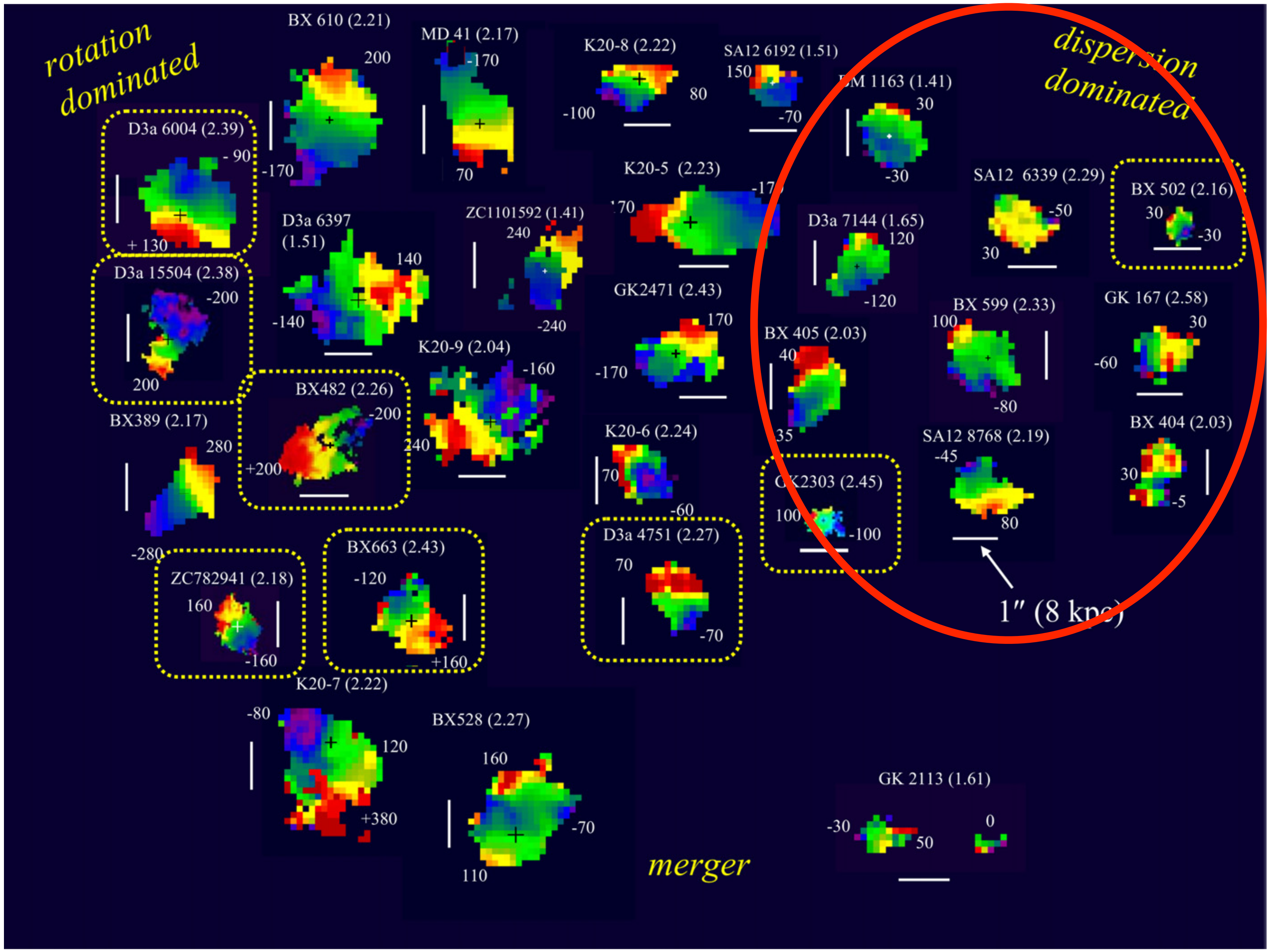
2013-2020

Observations with KMOS and ALMA will provide a comprehensive view of the predicted scenarios — **500-1000**

what are we to do by using ULTIMATE-Subaru?

wide-field imager
→ statistical study of nuggets
IFU
→ statistical study of population before nugget phase

Population before nugget phase

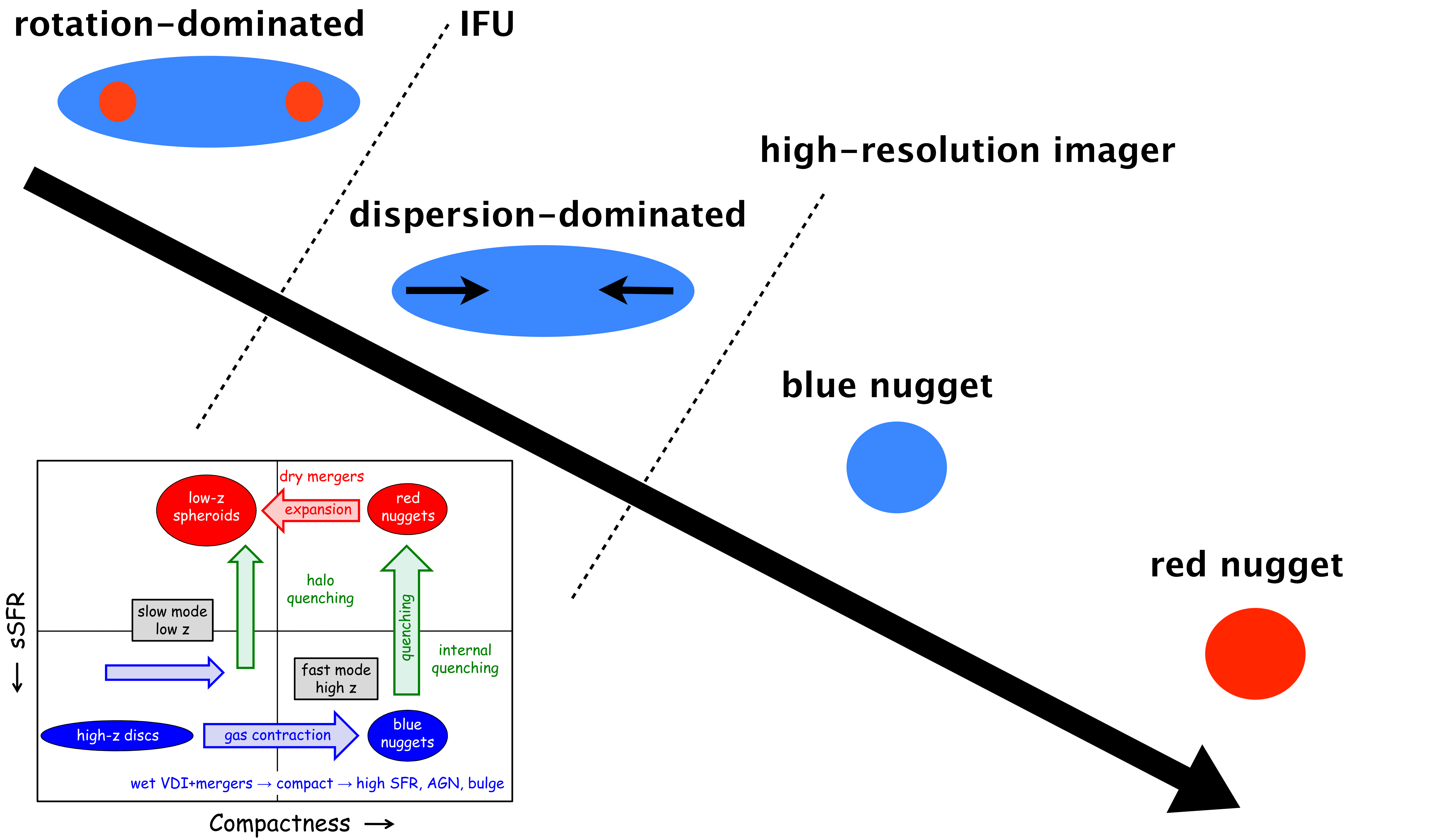


why is dispersion dominated?

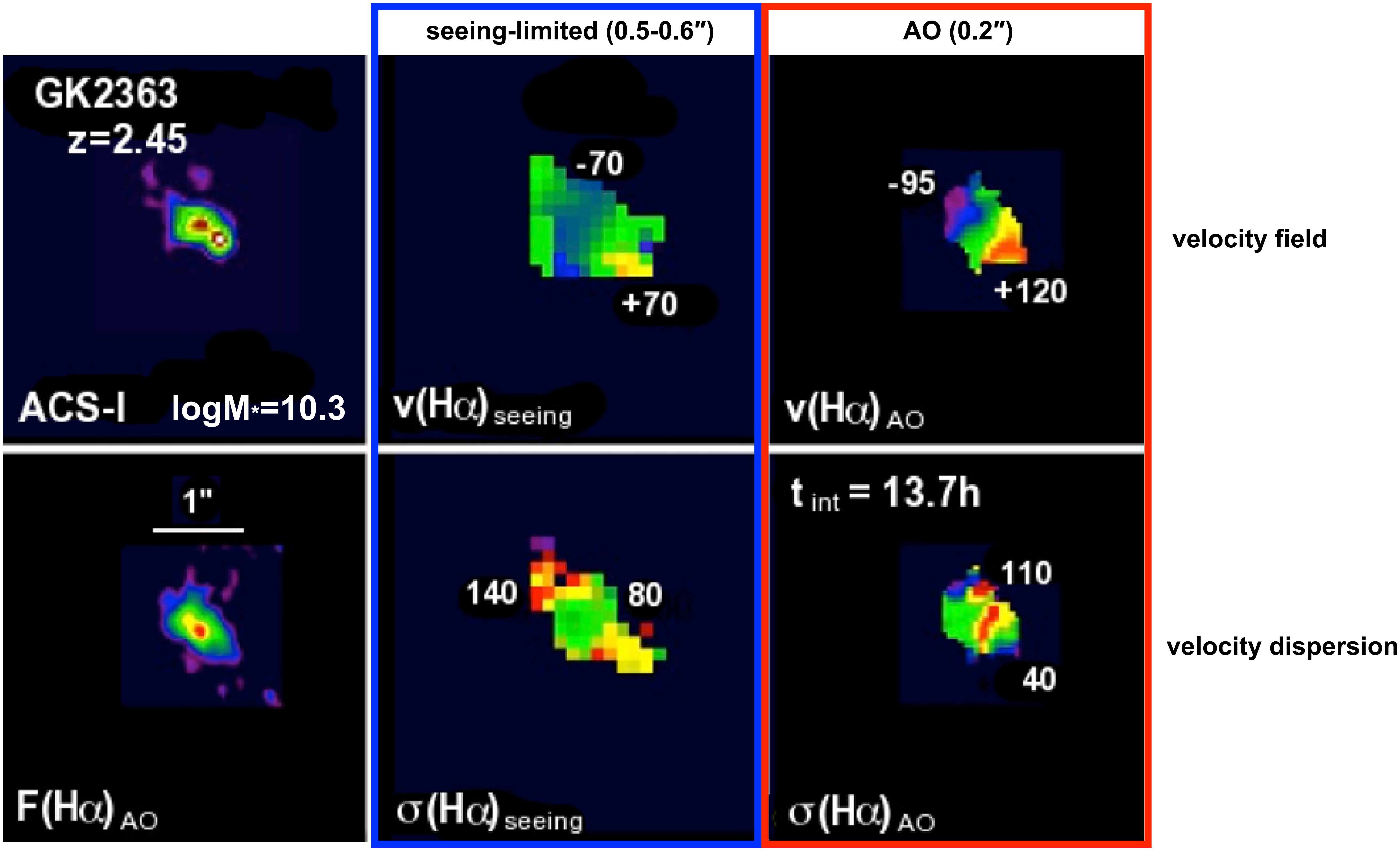
gas inflow is efficient?
candidates of nuggets?

Forster Schreiber+09

Population before nugget phase



Beam smearing effect



Newman et al. 2013

KMOS GTO programs (only high-z)

to my knowledge...

- **KMOS^{3D} (PI: Förster Schreiber)**
- **KMOS Kinematic Survey (PI: Sharples)**
- **KMOS Deep Survey (PI: Cirasuolo)**
- **KMOS clusters program (PI: Bender/Davies)**
- **VIRIAL (PI: Mendel)**

and so on.

star-forming

passive

	KMOS	**ULTIMATE** with GLAO	**SINFONI** with AO
spatial resolution	~0.6″	?	0.1-0.2″
multiplicity	24	?	1
sample size of large survey	**500-1000**	?	30-40

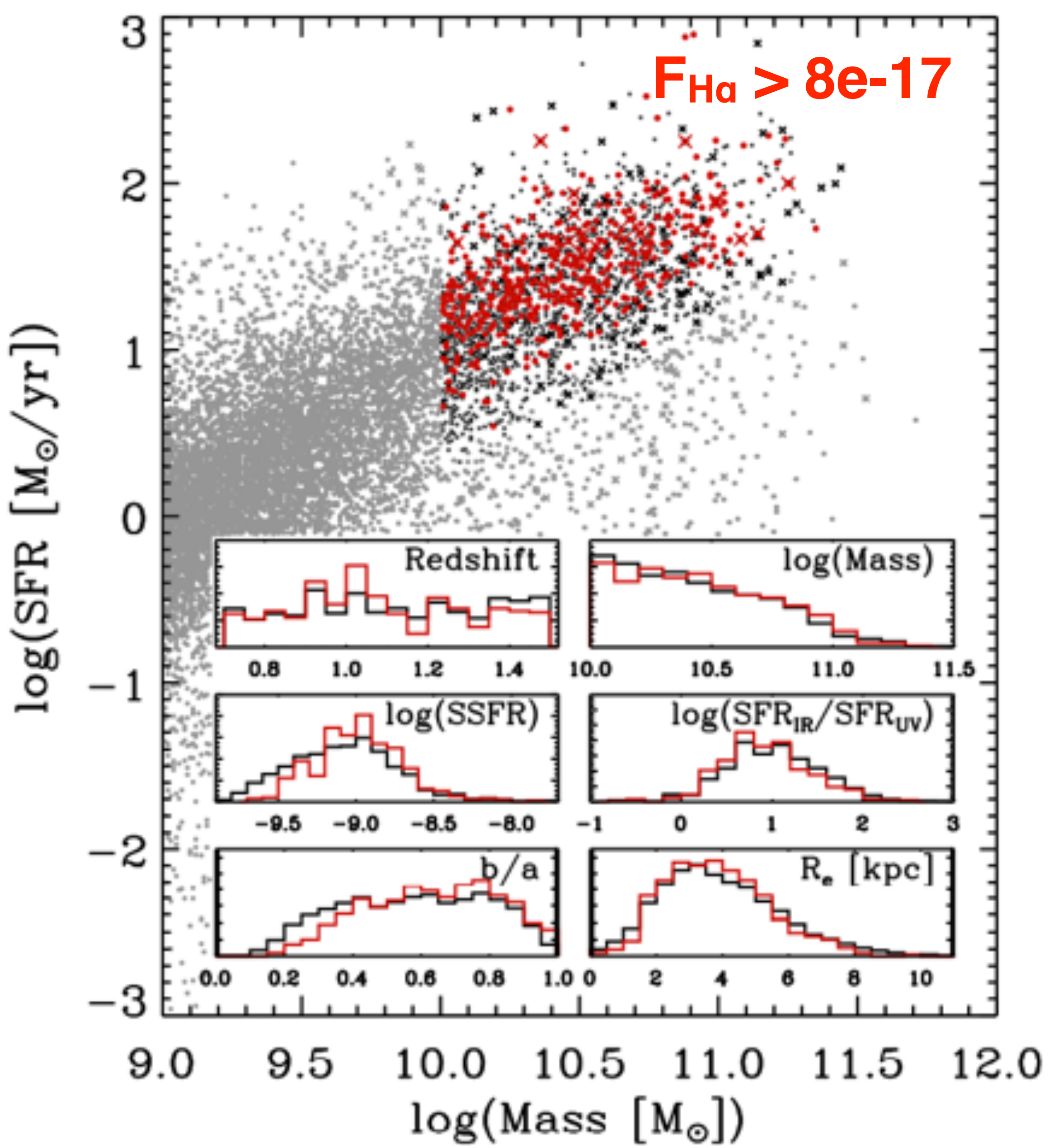
3D-HST sample in CANDELS field

Selection	N (Total) in five CANDELS field	N/13.6′FoV
$0.7 < z < 1.5$, $\log M_* > 10$	3115 galaxies	**~300**
$F_{H\alpha} > 8e-17$	636 galaxies	**60-80**

If we target mass-complete sample,
52 are reasonable.

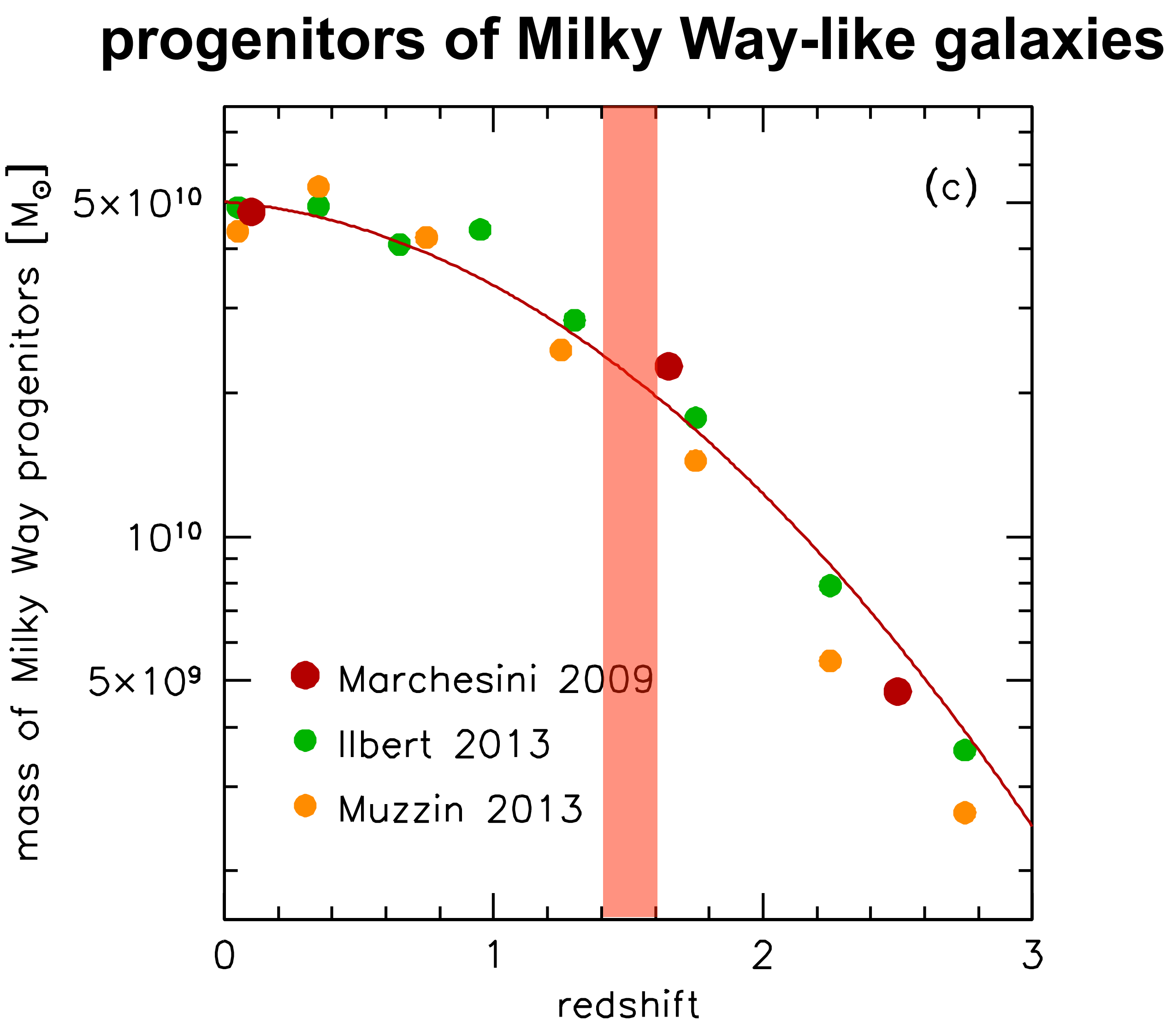
If we target only SFGs with strong Hα emission,
26 or 52 bundles are reasonable.

Note that these are targets of KMOS^{3D} project.
KMOS: $F_{H\alpha} > 8e-17$
ULTIMATE-Subaru: $F_{H\alpha} > 4e-17$?
It depends on the capability of ULTIMATE-Subaru.

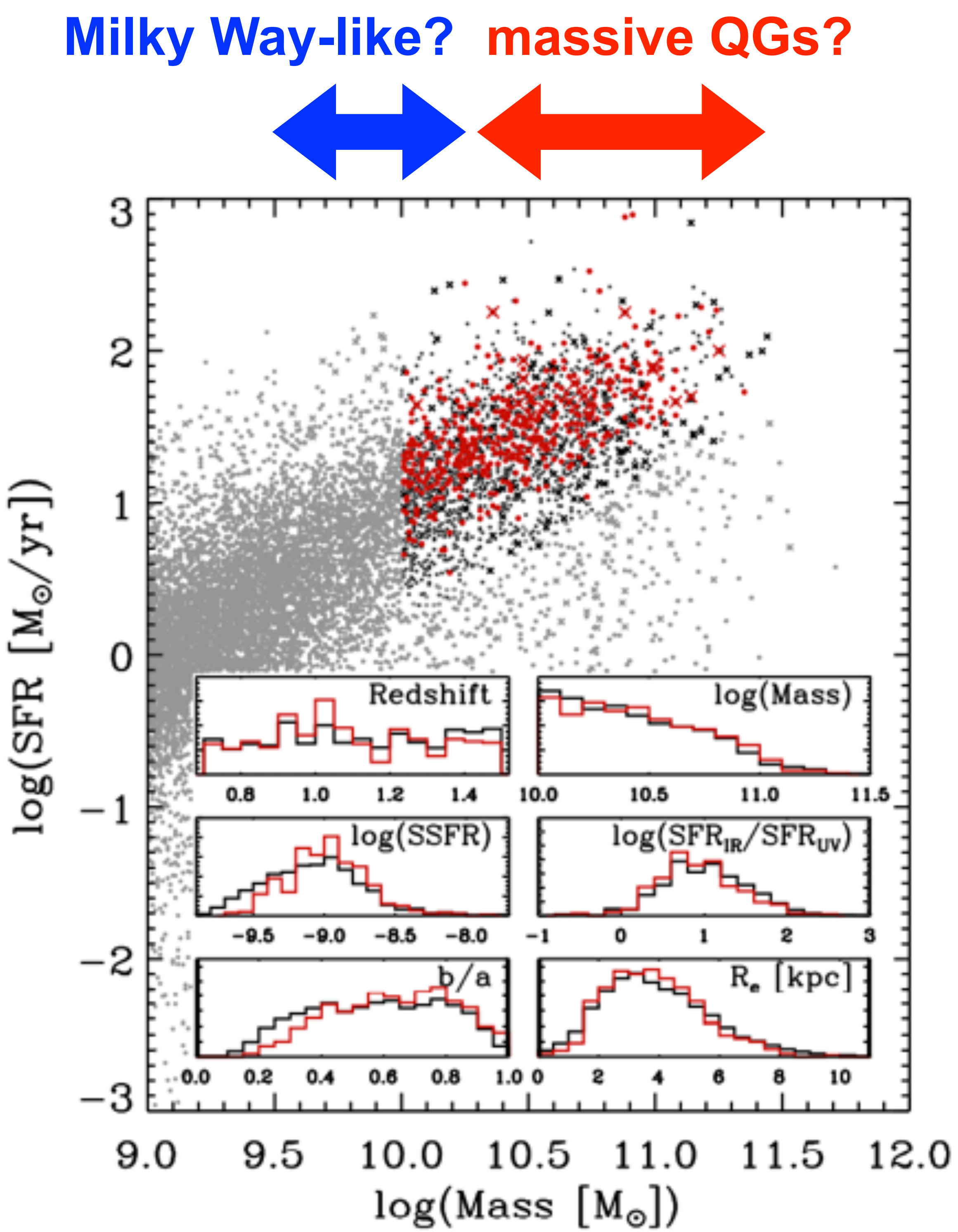


Wuyts et al. 2013

Progenitors of Milky way-like galaxies



$M_* = 2 \times 10^{10}\ M_{sun}$ at z~1.5

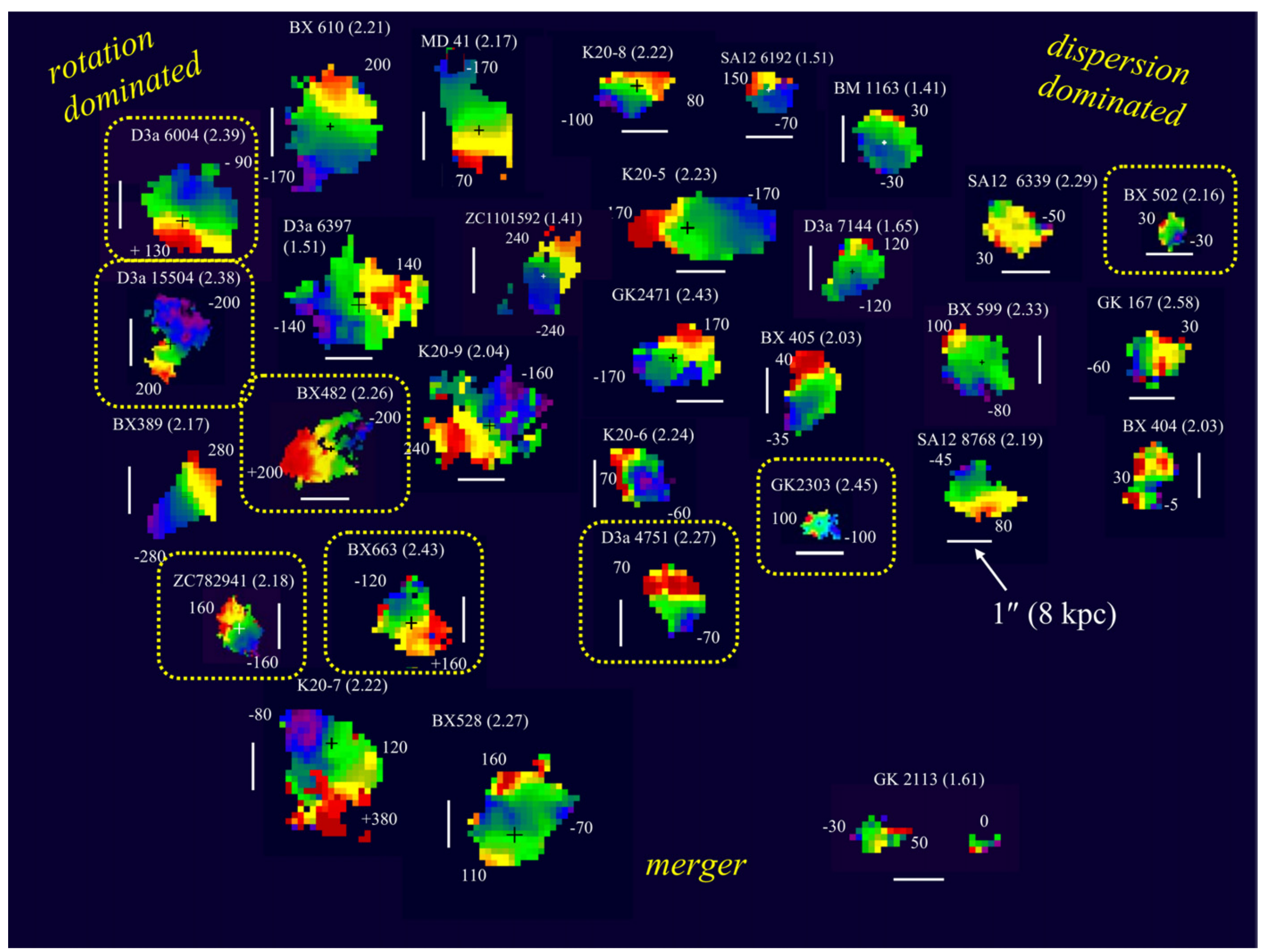


van Dokkum+13

Summary

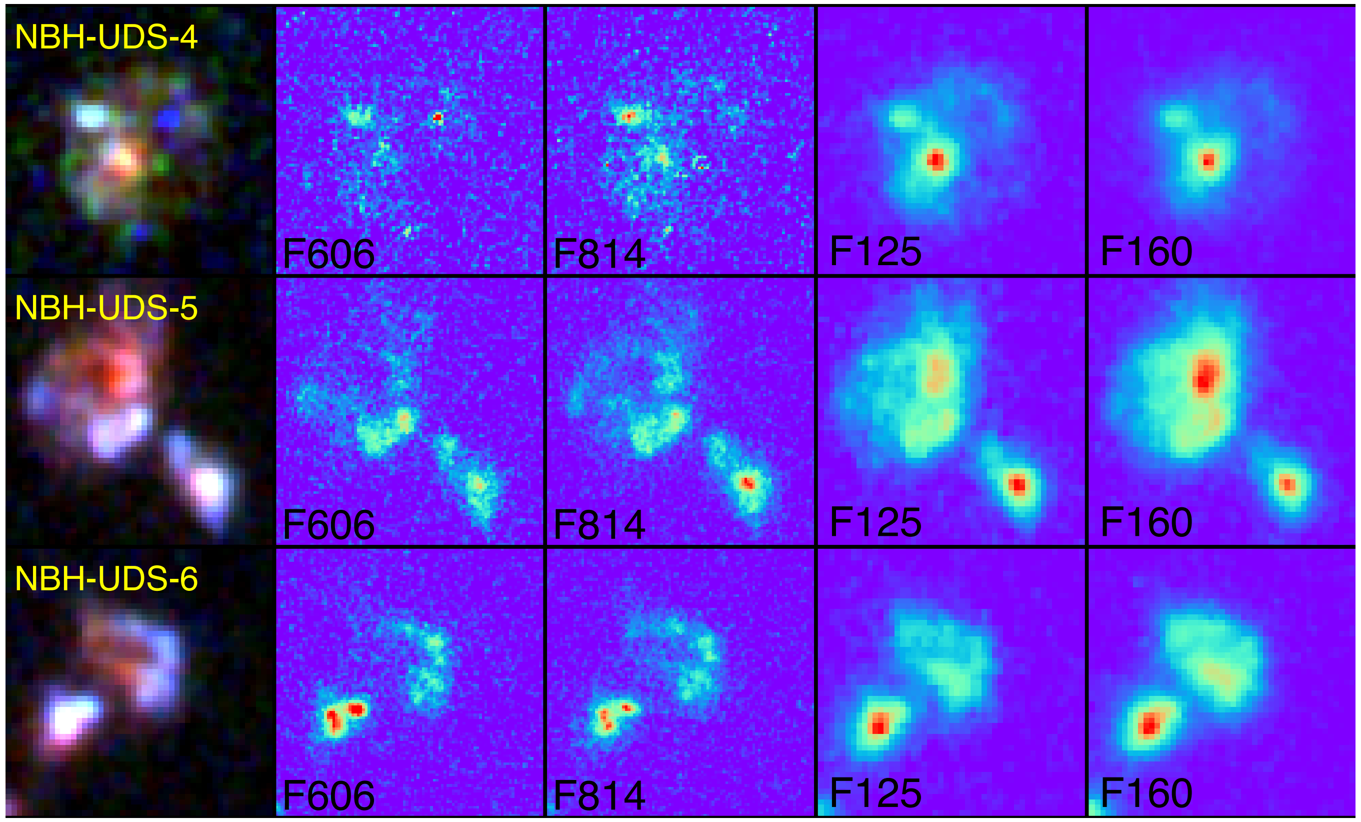
straightforward strategy with ULTIMATE-Subaru

1. update the bottom panel for targeting the mass-complete sample
2. investigate the properties (σ, V_{rot}, Q) in multi-parameter spaces (stellar/dynamical mass, SFR, redshift, environment...)
3. provide a comprehensive view of the formation scenario of massive galaxies



My answers about specifications

- sampling, sensitivity and resolution
we want to obtain kinematic information from galaxies with F_{line}=(4-8)e-17 and source size of 0.5″-1.5″
- multiplicity
26 or 52
- uniqueness
I'm not sure...



3″×3″

←SFGs at z~1.5
(Sobral et al. 2013)