The Structure of Starforming Galaxies at z ~ 2 (as seen through SINFONI)

Alvio Renzini, IPMU, May 15, 2013

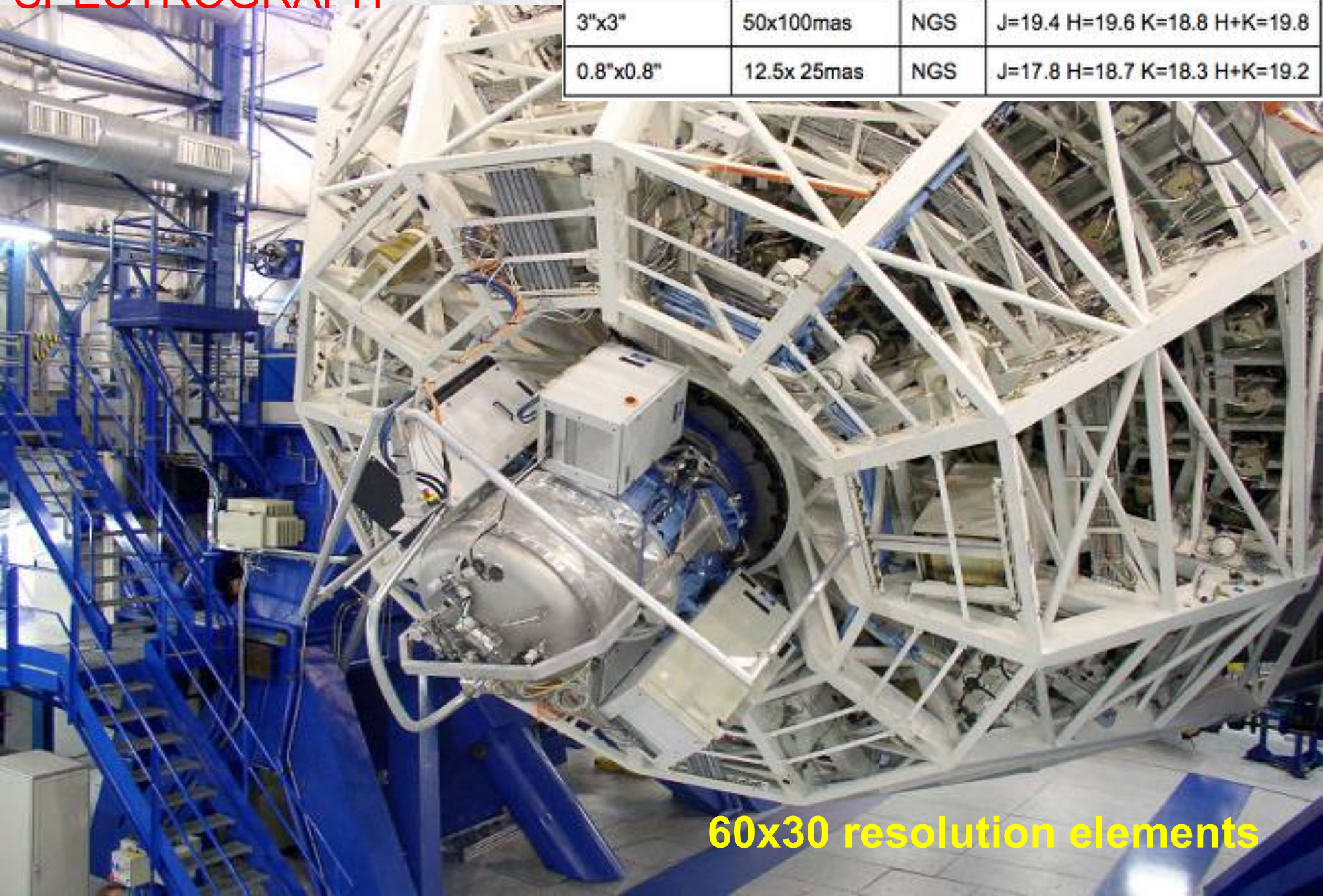
Outline:

- Culling targets for SINFONI 3D spectroscopy
- Large disks, mergers, and strange compact galaxies
- The gas content of SF z~2 galaxies
- Hints on the formation of bulges, thick disks, etc.

Based on the work of the zCOSMOS and SINS Teams:
S. Lilly, AR, G. Zamorani, C. Mancini, M. Carollo, Y. Peng, L. Pozzetti, N Förster Schreiber, R. Genzel, L. Tacconi, G. Cresci, S. Newman and many more)

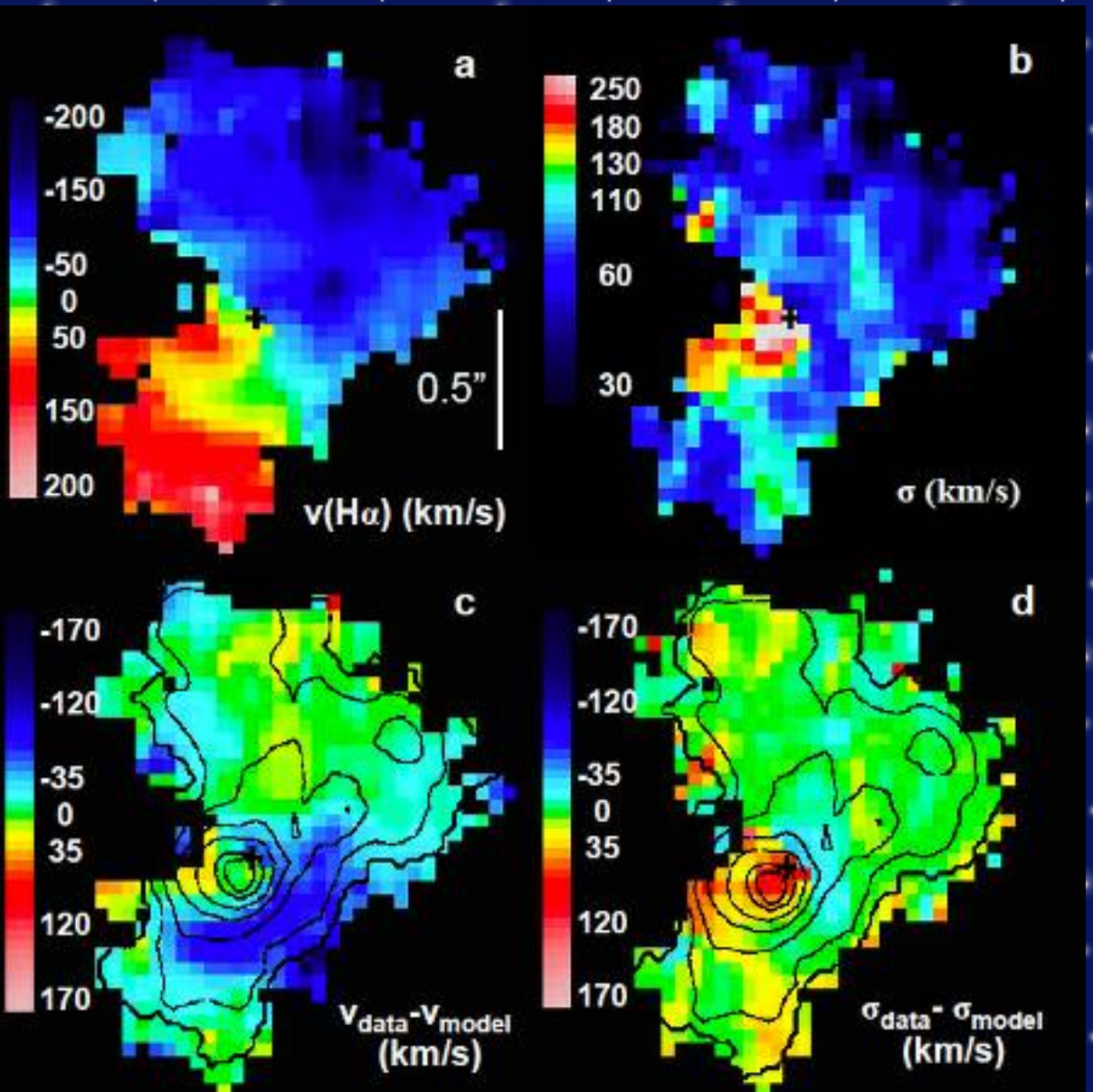
SINFONI 3D AO-FED SPECTROGRAPH

Field of View	Spatial Scale	Mode	Limiting Magnitudes
8"x8"	125x250mas	noAO	J=20.2 H=19.9 K=17.9 H+K=19.6
3"x3"	50x100mas	NGS	J=19.4 H=19.6 K=18.8 H+K=19.8
0.8"x0.8"	12.5x 25mas	NGS	J=17.8 H=18.7 K=18.3 H+K=19.2



60x30 resolution elements

2006: a BzK galaxy @ z=2.38 w SINFONI



Hα kinematics of BzK15504 in the Deep3a field of EIS

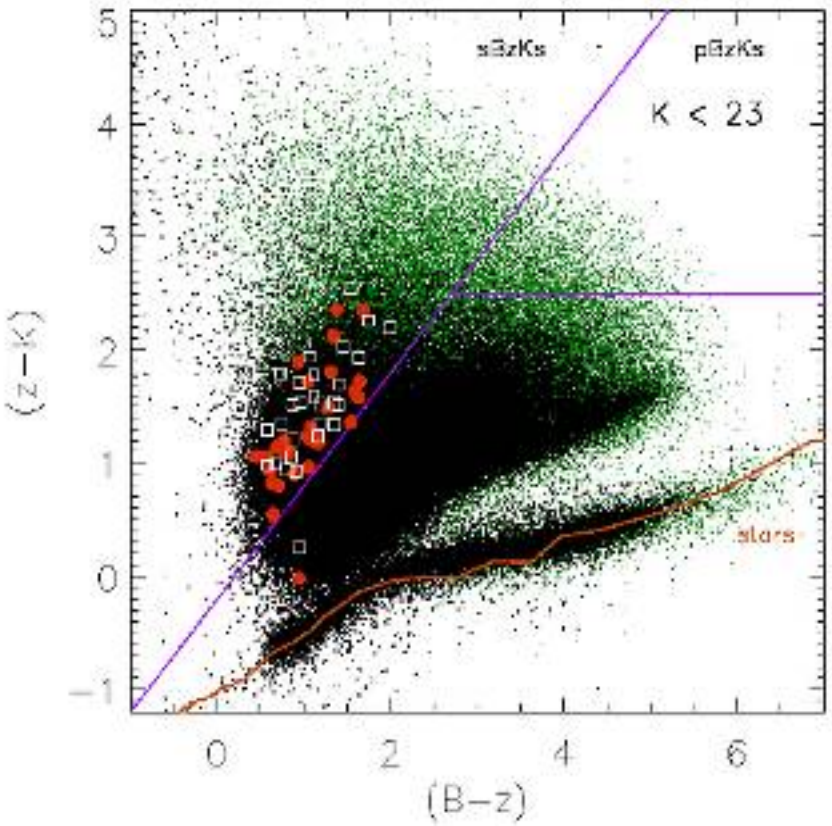
(Kong et al. 2006)

Genzel et al 2006, Nature, 442, 786

2007: zCOSMOS-Deep (PI S. Lilly) starts the mass production of suitable targets for the SINFONI follow-up

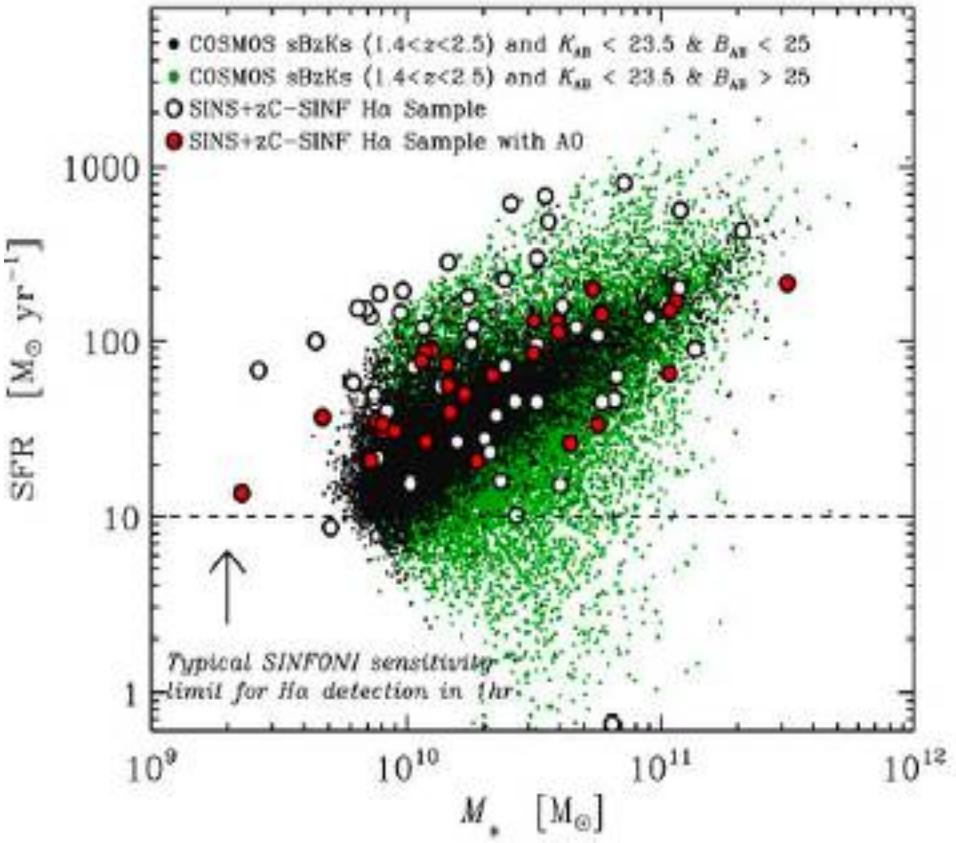
- Among VIMOS targets (mostly sBzKs) pick those with a suitable star nearby for NGS/LGS
- Place them as "compulsory" targets in VIMOS masks
- Priority for spectra extraction and redshift measure for them
- Check if the redshift is such to have Hα in the K band & clear from OH/telluric contaminations
- If so, proceed with SINFONI "pre-imaging"
- If Hα flux is strong enough then the target is promoted to >5h AO-Assisted observations

The Targets



Black: B<25

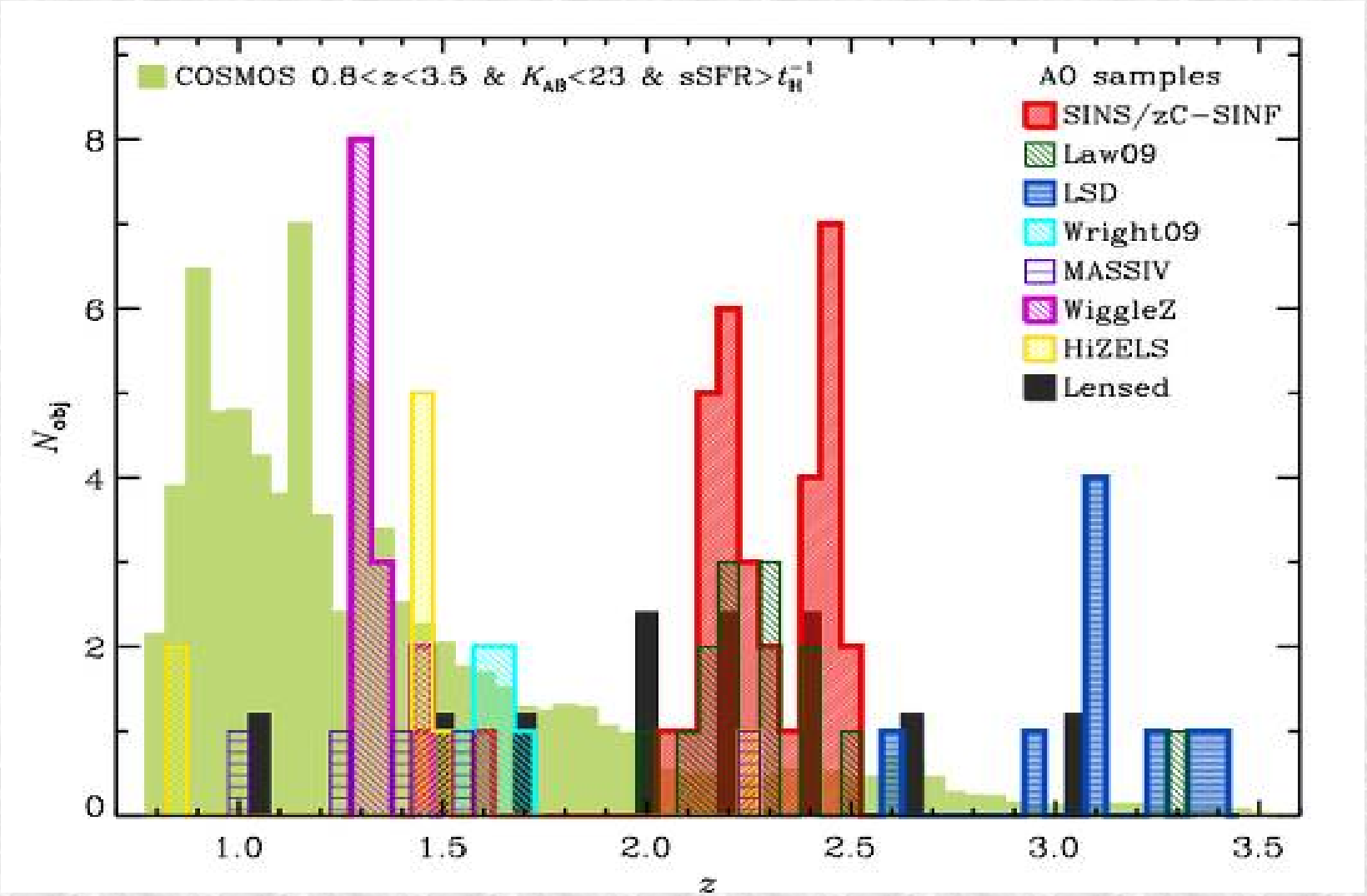
Green: B>25

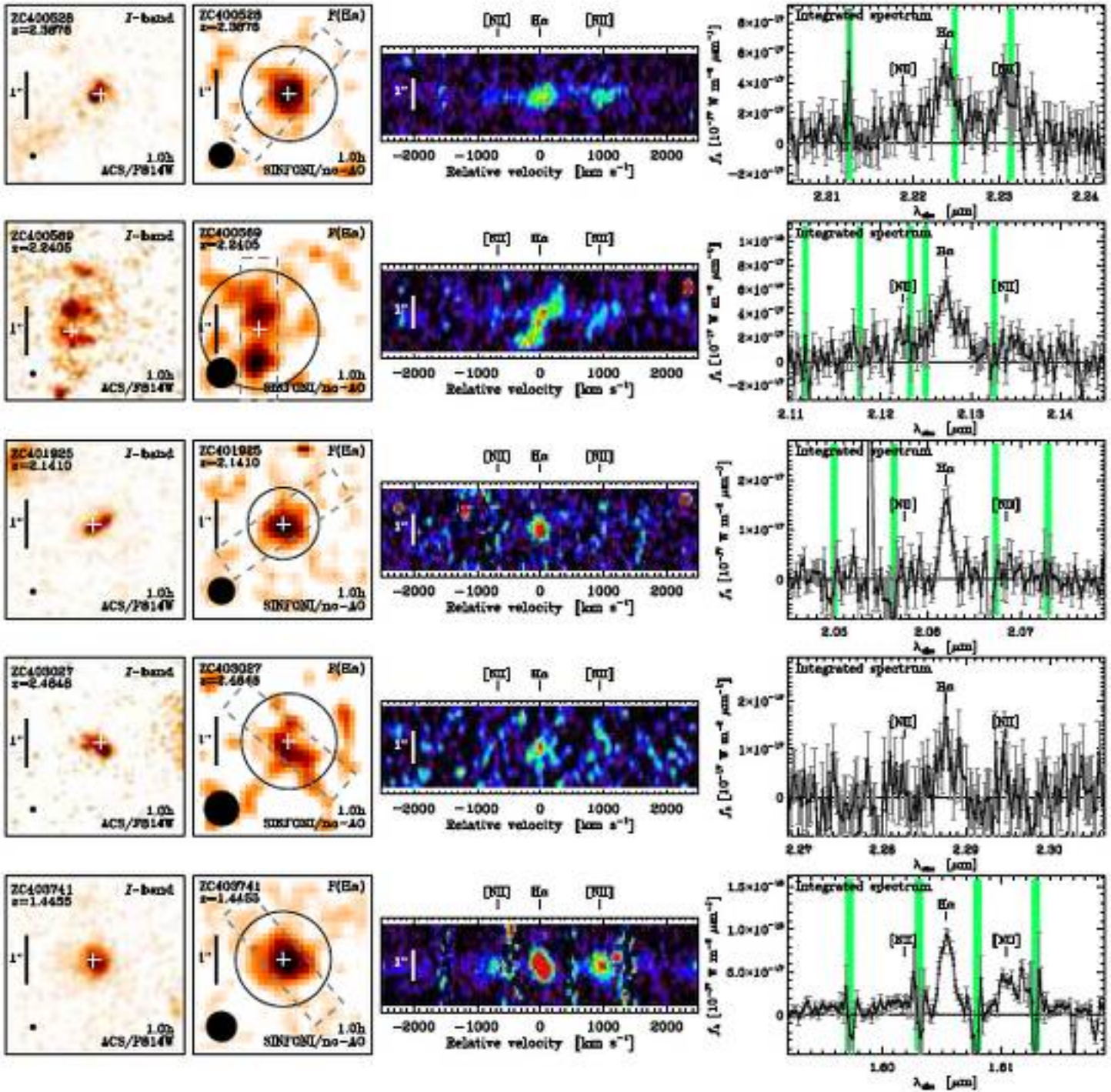


Mancini et al. 2011

Many Years Later

The SINS/zC-SINF project in contest 35 galaxies with AO data

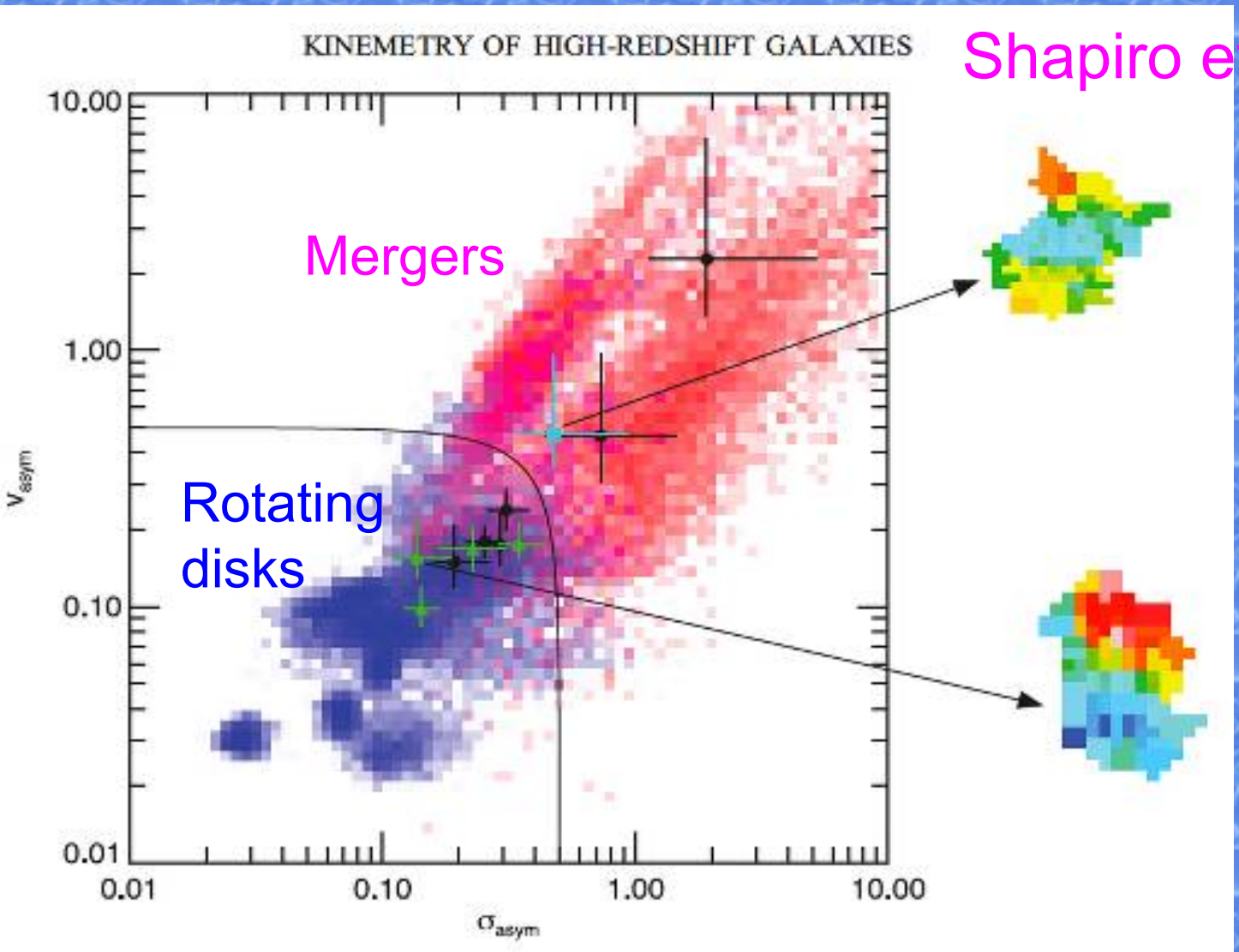


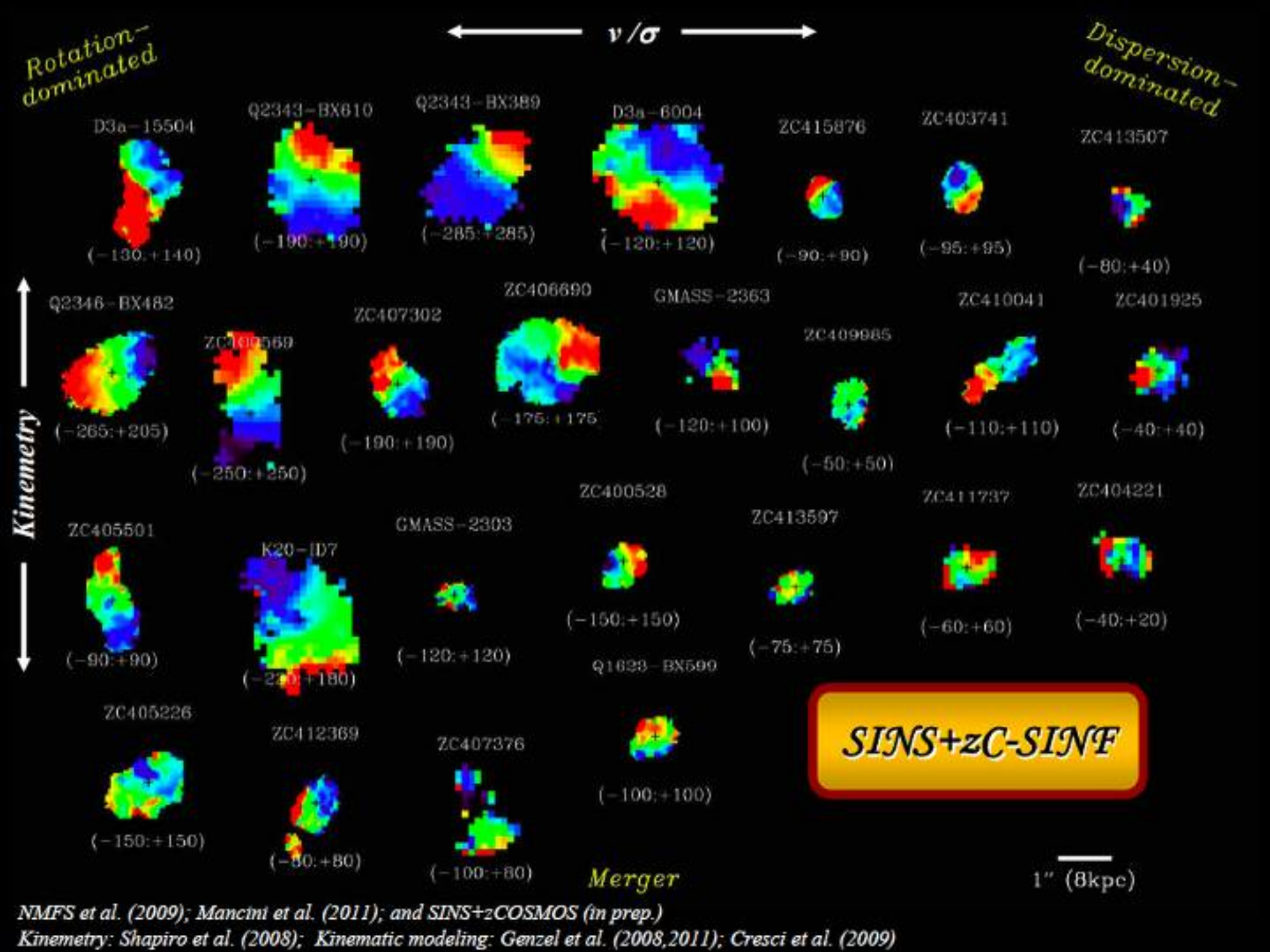


Bookkeeping
Pre-imaging
Data

Mancini et al. 2011

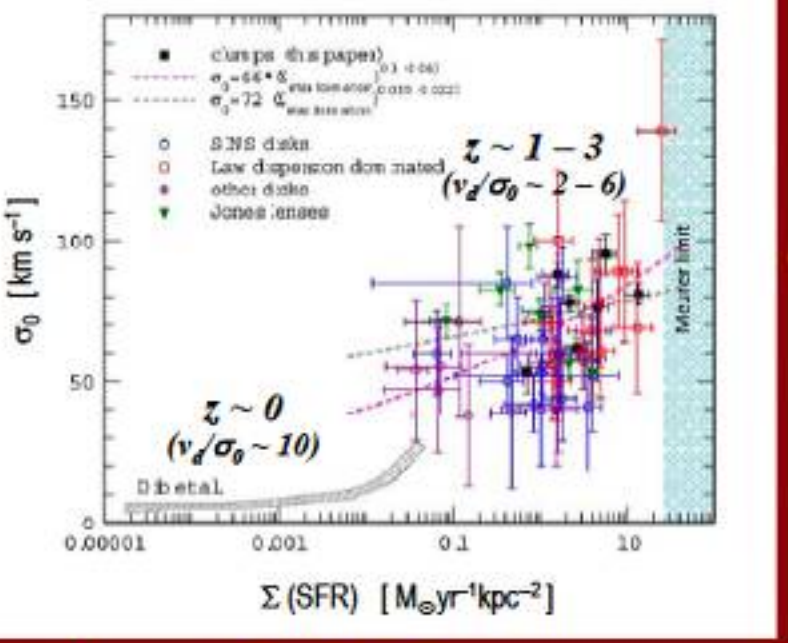
“Kinemetry” to classify the dynamical structure of galaxies

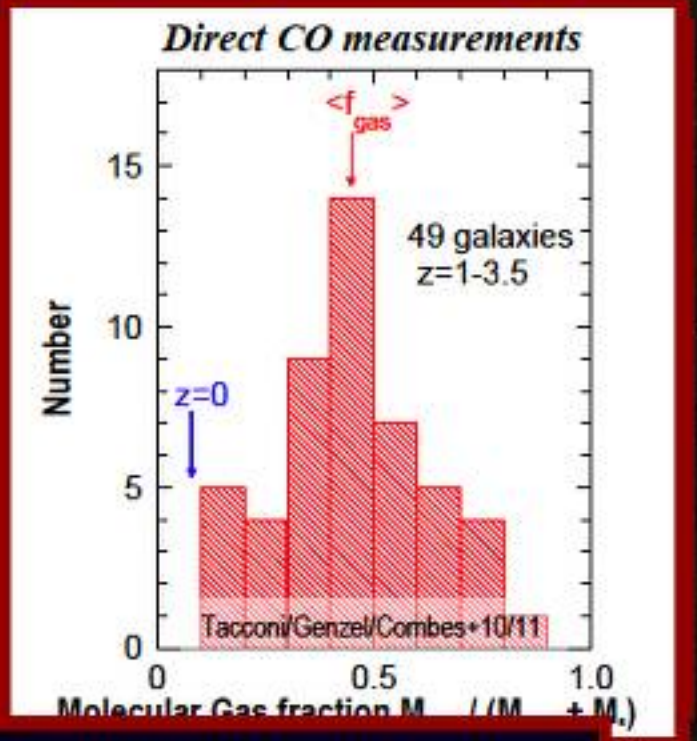


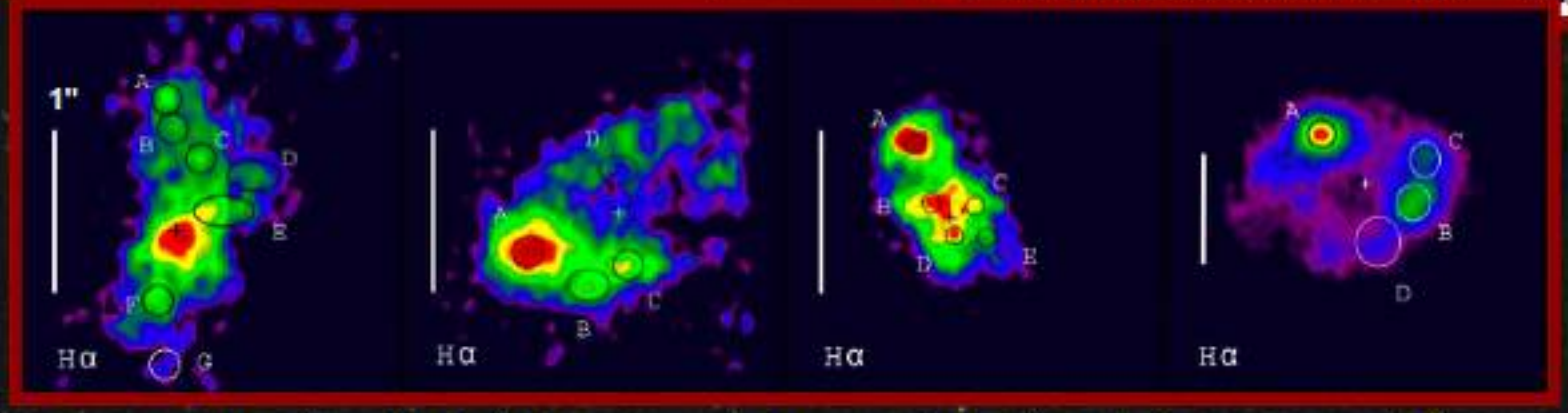


NMFS et al. (2009); Mancini et al. (2011); and SINS+zCOSMOS (in prep.)
Kinemetry: Shapiro et al. (2008); Kinematic modeling: Genzel et al. (2008,2011); Cresci et al. (2009)

Turbulent Gas-Rich Clumpy Disks at High z

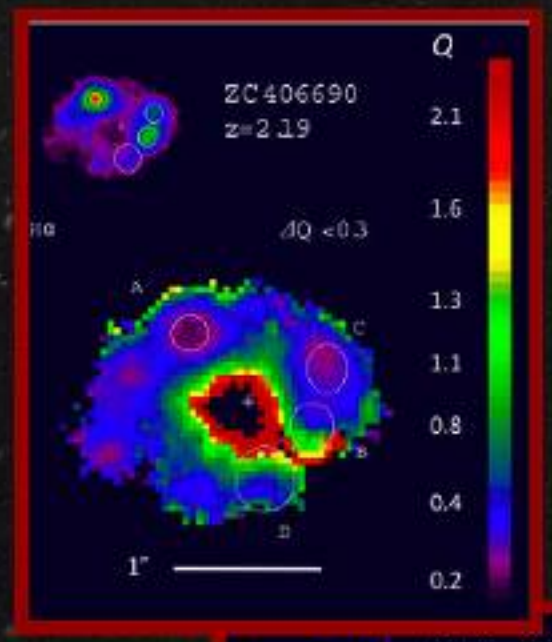




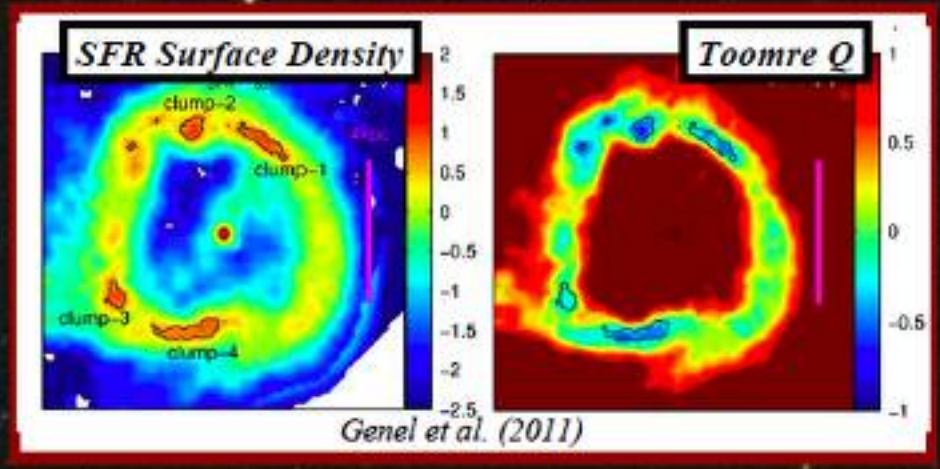


SINS+zC-SINF / Genzel+06/08/10/11; Cresci+09; Tacconi+08/10; Daddi+10; Erb+06; NMFS+06/09/11

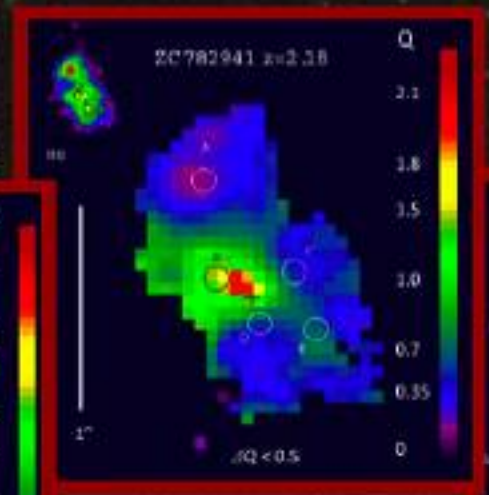
Clumps and Disk Instabilities

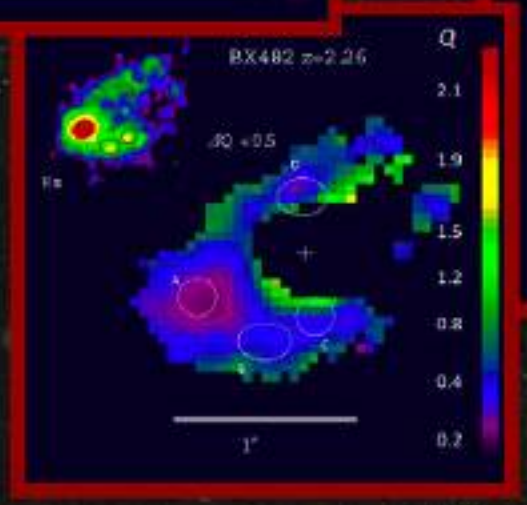


$$Q_{gas} = \frac{\sigma_0 \kappa}{\pi G \Sigma_{gas}}$$

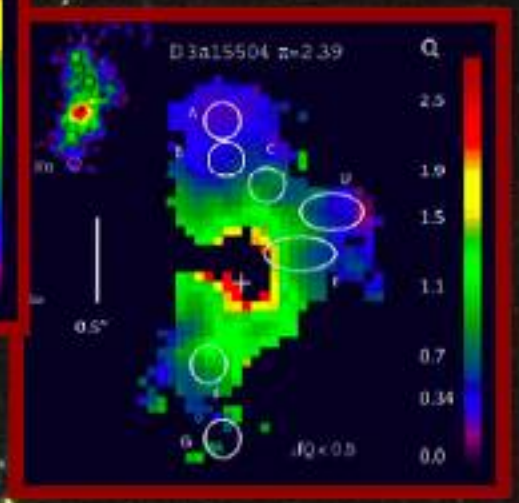


Genel et al. (2011)



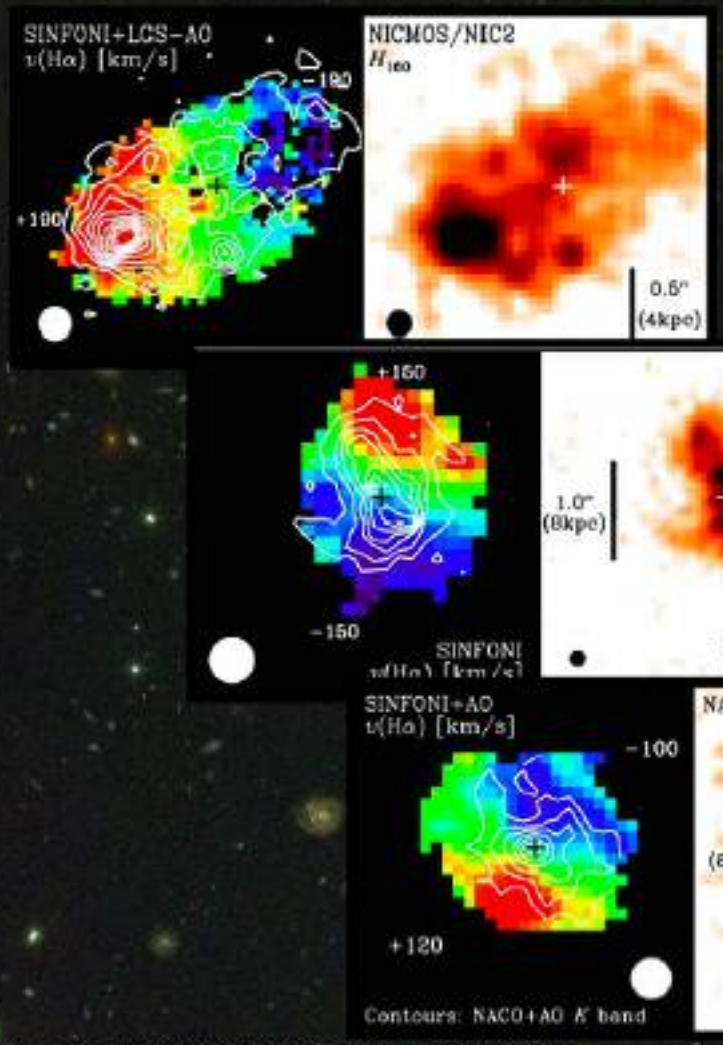


Genzel et al. (2011)

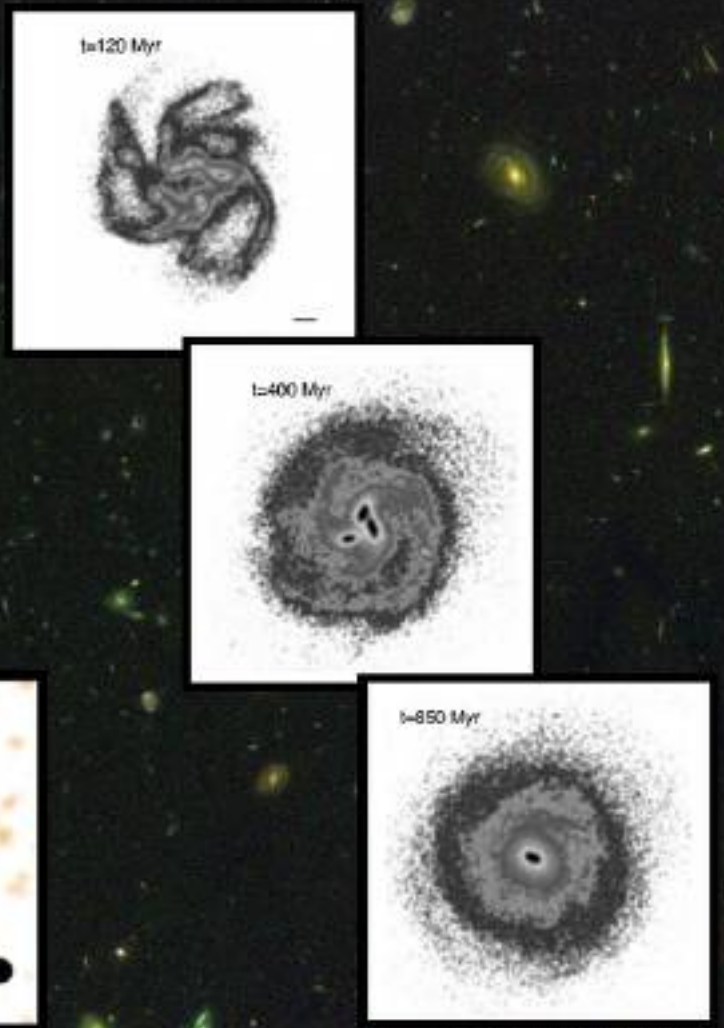


Bulge Formation in Gas-rich High z Disks

In-situ Observations



Numerical Simulations



Genzel et al. (2008/11); NMFS et al. (2011b)

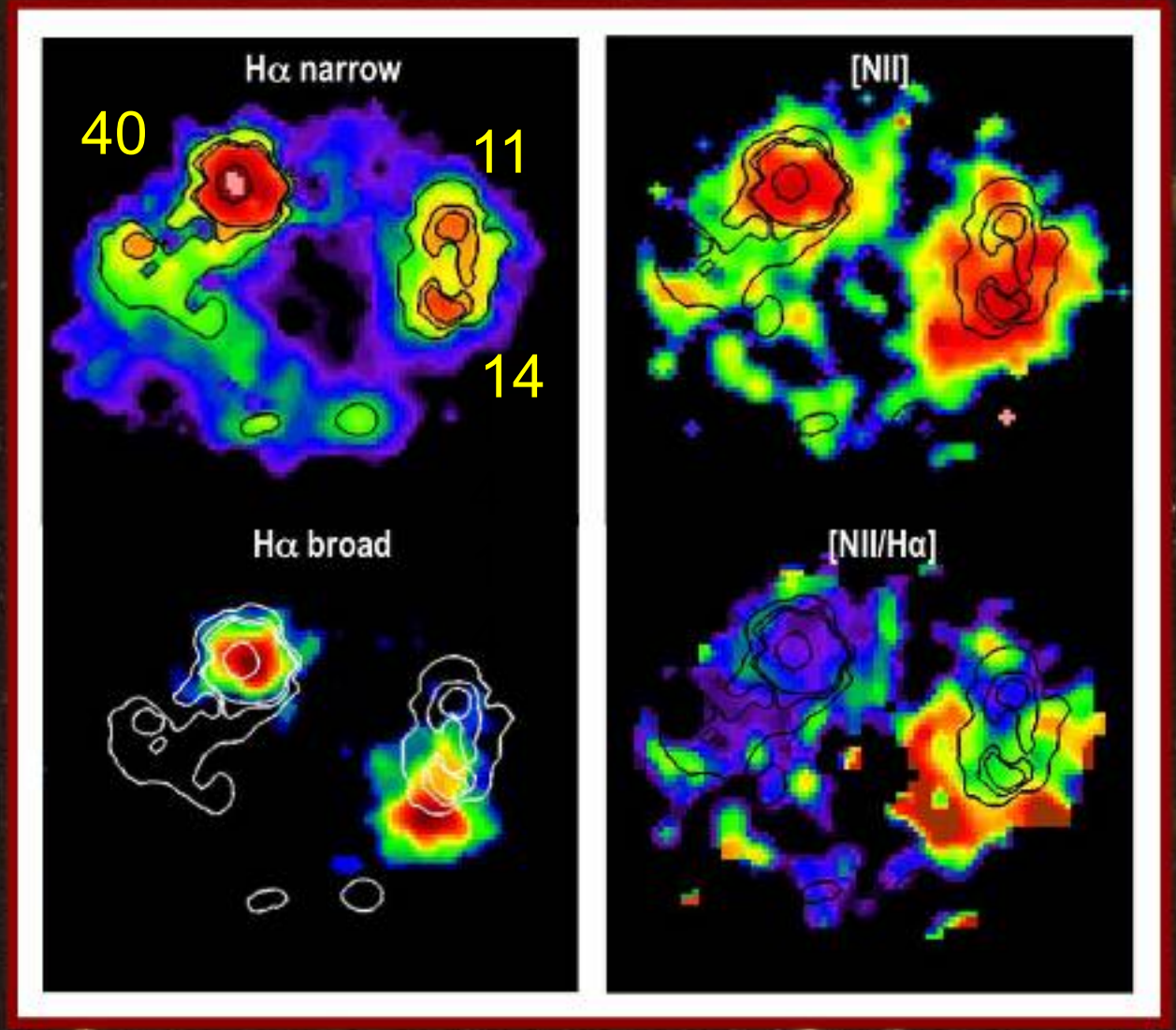
Bournaud et al. (2007-2009)

Also, e.g., Noguchi99; Immeli+04; Governato+06/07; Carollo+07; Burkert+09; Dekel+09; Aumer+10; Ceverino+10; Genel+11

Mapping Star-forming and Wind Regions

ZC406690 (z=2.19)

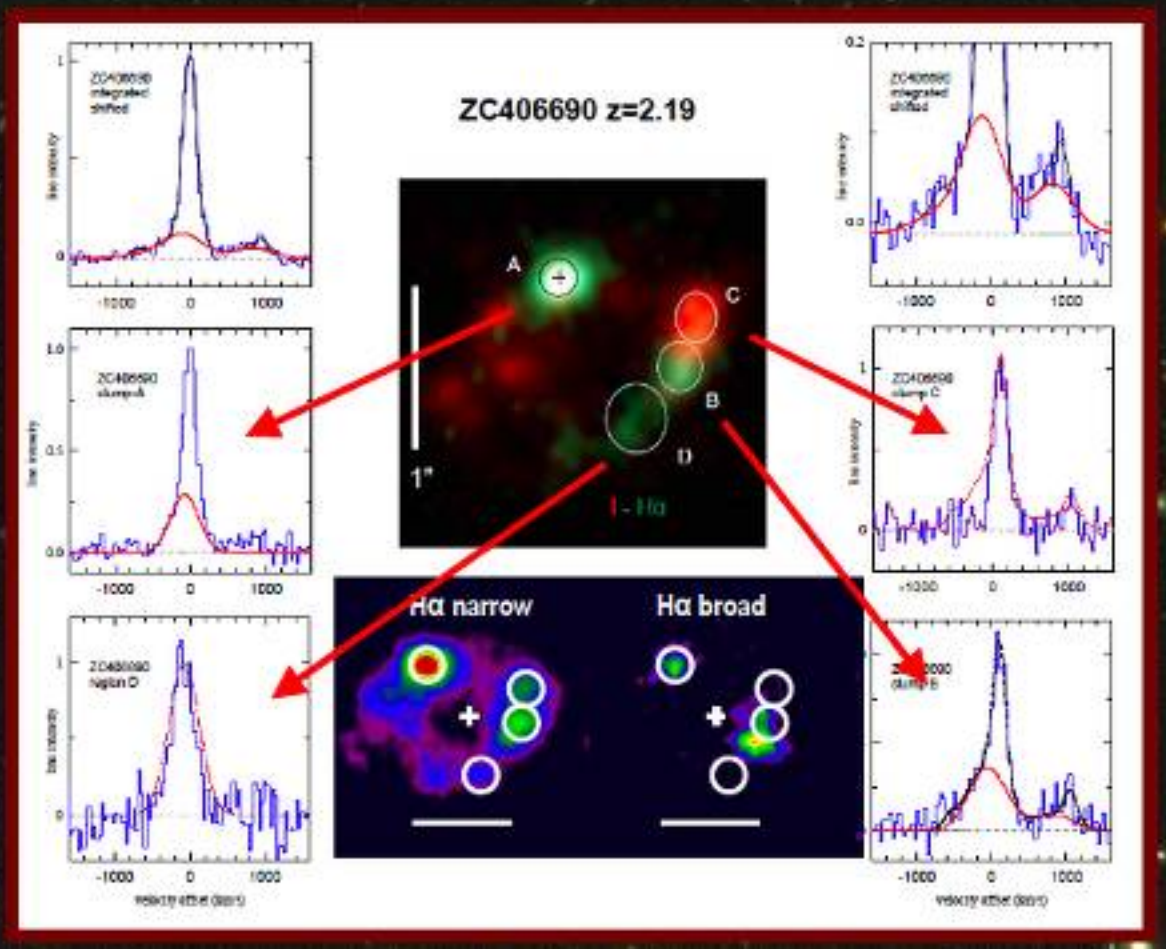
Global SFR=~200 $M_\odot$/yr

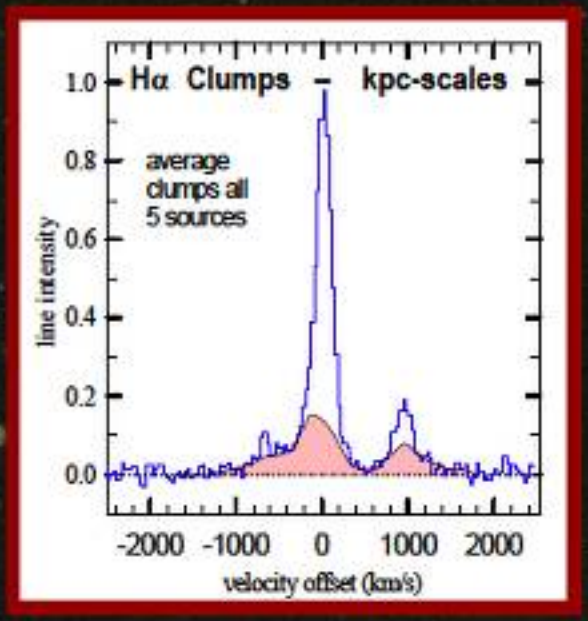


Genzel et al. (submitted); Genzel et al. (2011)

Vigorous Stellar Feedback in Clumps

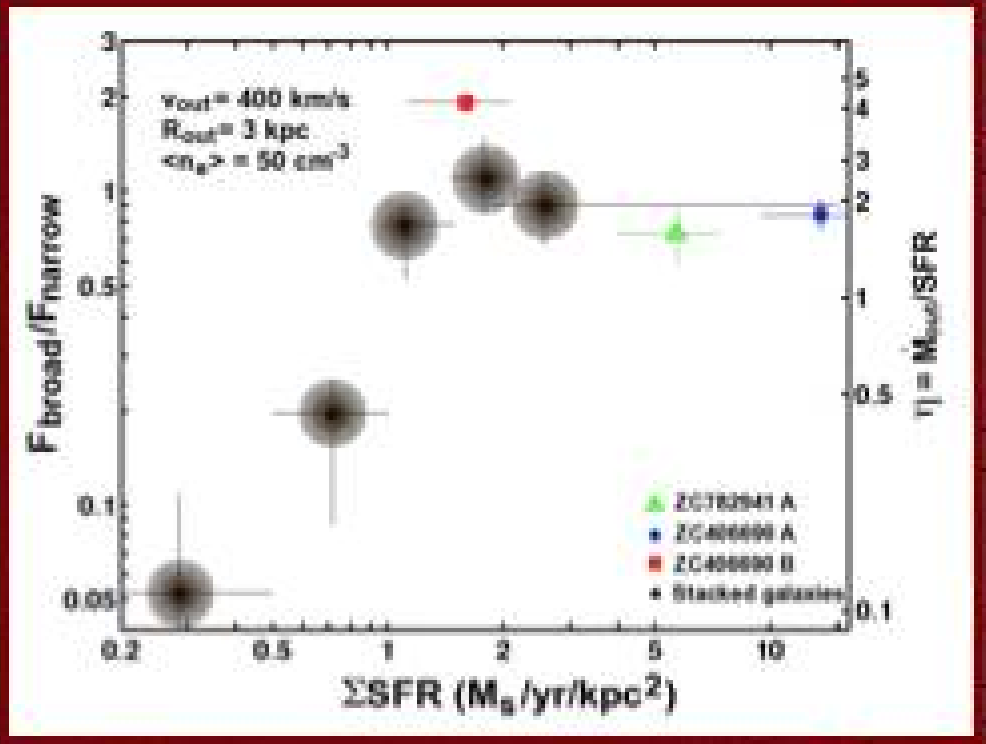
- *Clump mass outflow rates ~ 1 – 10 x SFRs*
- *Lifetimes of most actively star-forming clumps limited to a few 100 Myrs*

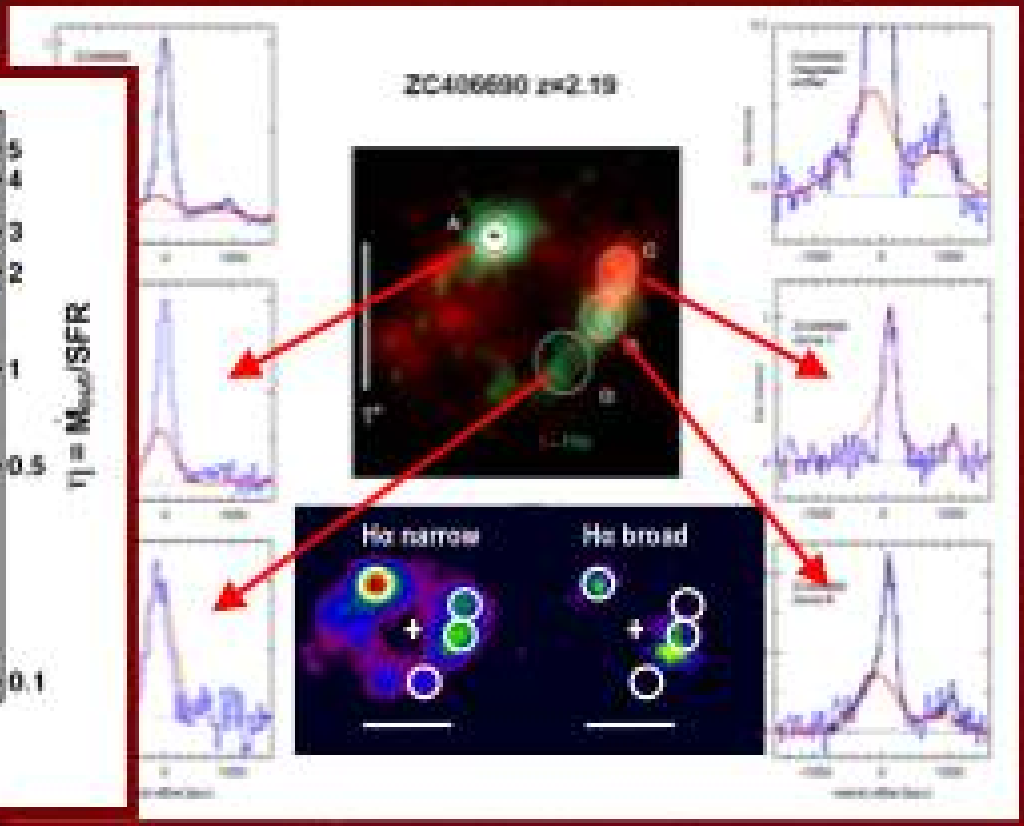




Genzel et al. (2011); Newman et al. (in prep.)

Vigorous SF-driven Outflows

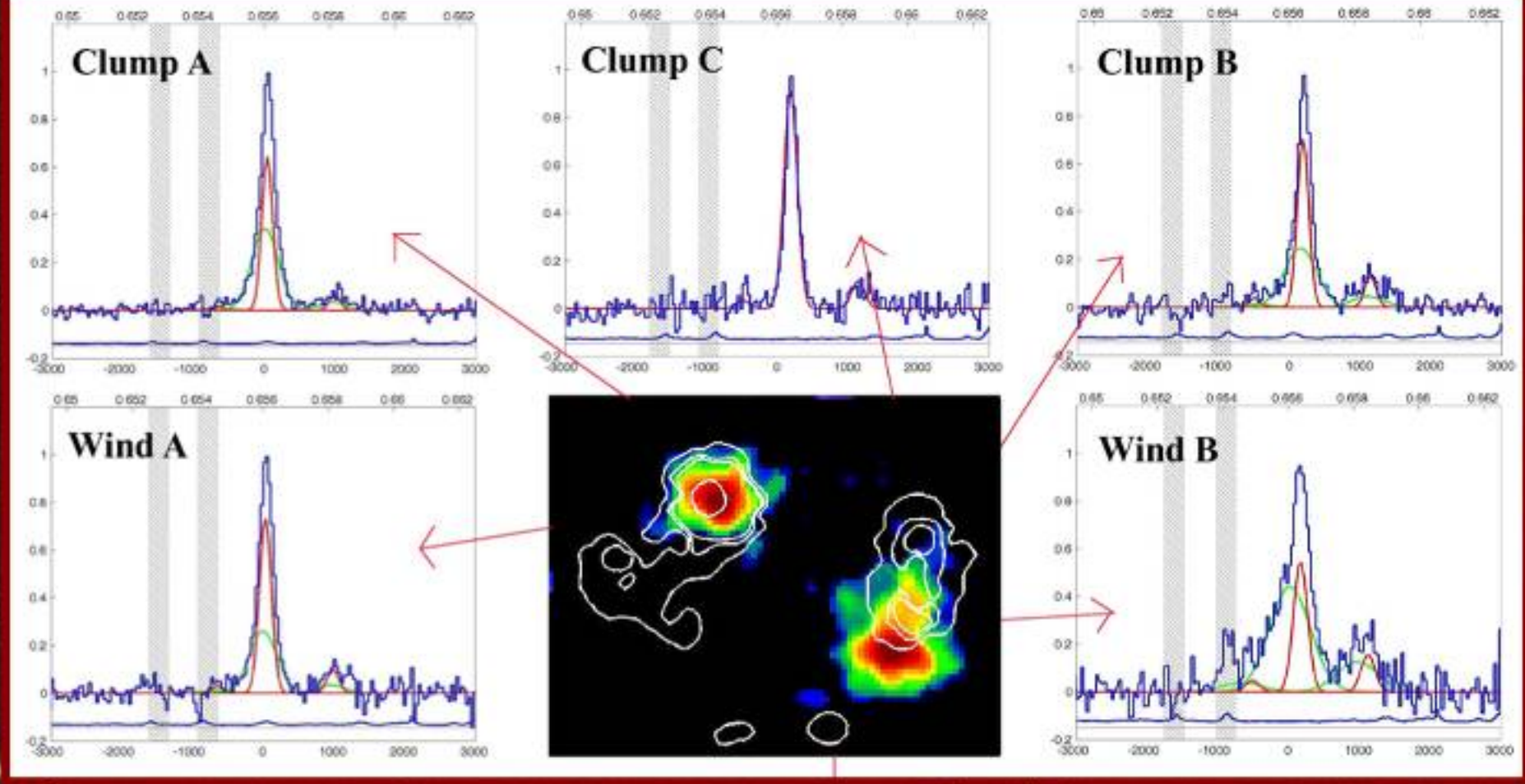




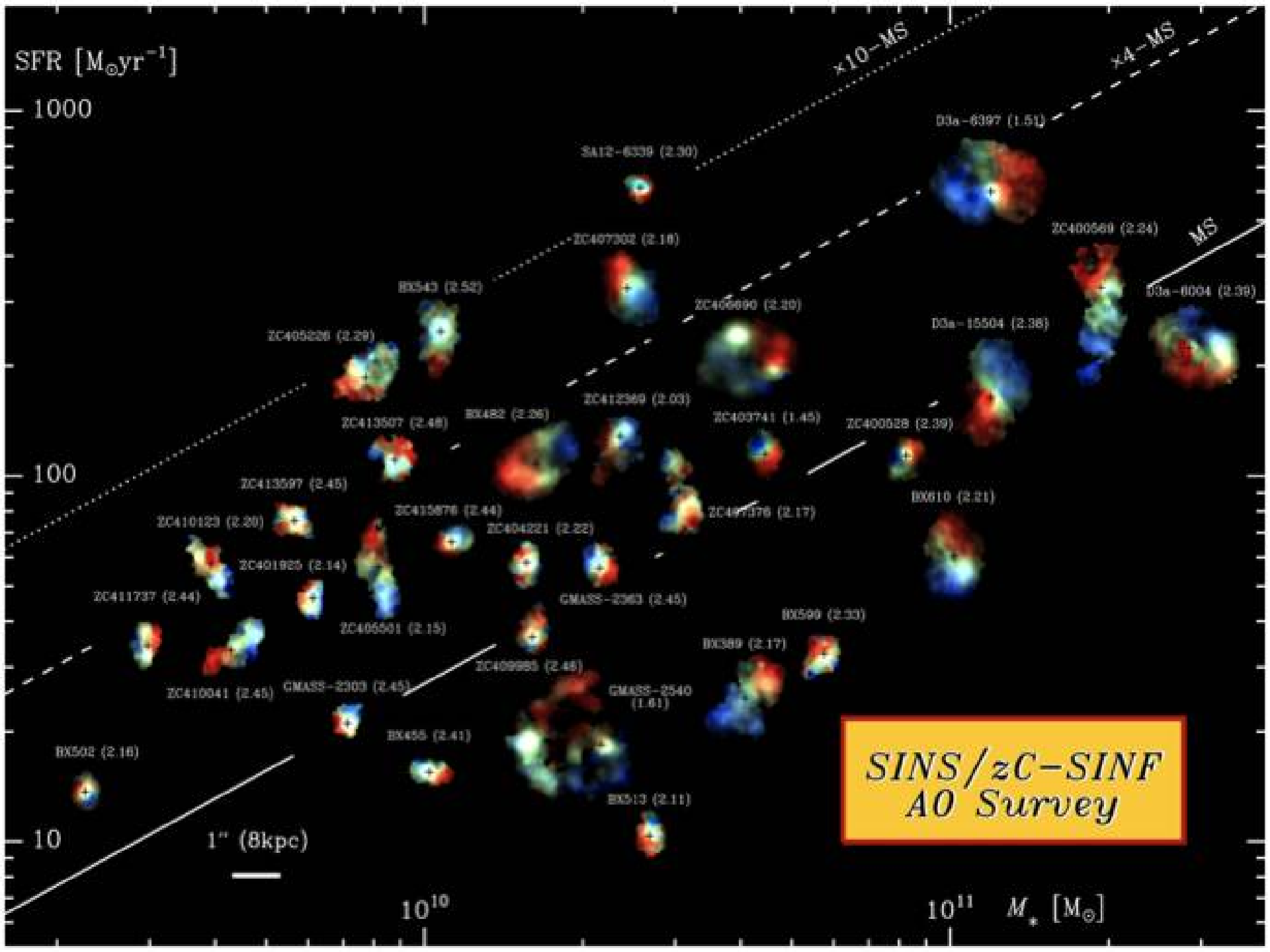
Genzel et al. (2011); Newman et al. (2012a,b); Genel et al. (2012); Shapiro et al. (2009)
Also, e.g., Pettini+00; Shapley+03; Weiner+09; Steidel+10; Coil+11; Kulas+11; Law+12b; Kornei+12; Heckman+00; Martin+05; Rupke+05

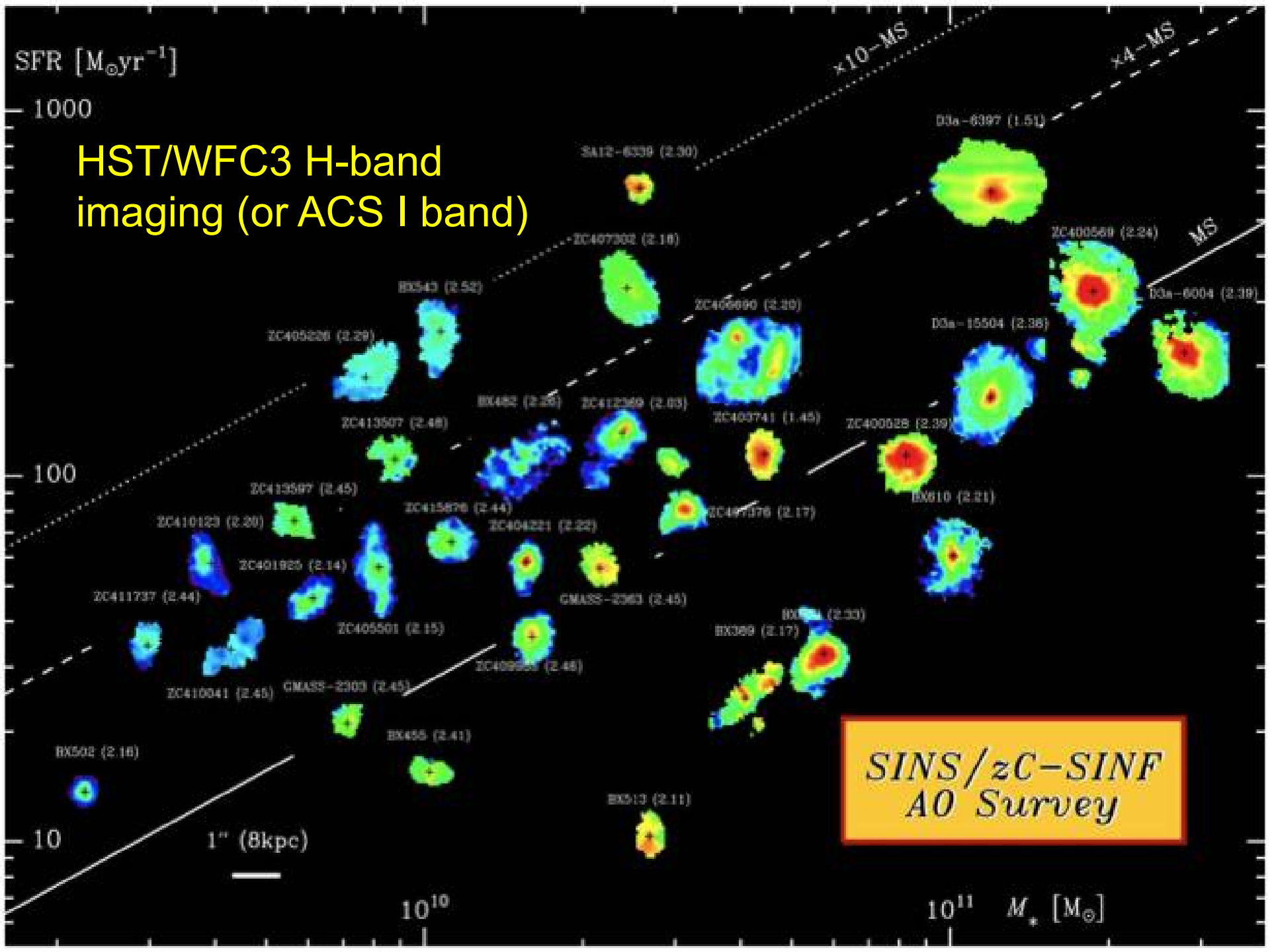
Evidence for Outflows from Clumps

ZC406690 (z=2.19)



Newman et al. (subm.); Genzel et al. (2011)


SFR [M⊙yr⁻¹]
1000
100
10
×10-MS
×4-MS
MS
SA12-6339 (2.30)
D3a-6397 (1.51)
ZC407302 (2.18)
ZC400569 (2.24)
BX543 (2.52)
D3a-6004 (2.38)
ZC406690 (2.20)
ZC405226 (2.29)
D3a-15504 (2.38)
ZC412369 (2.03)
ZC413507 (2.48)
BX482 (2.26)
ZC403741 (1.45)
ZC400528 (2.39)
ZC413597 (2.45)
BX610 (2.21)
ZC415876 (2.44)
ZC410123 (2.20)
ZC404221 (2.22)
ZC401925 (2.14)
ZC411737 (2.44)
GMASS-2363 (2.45)
ZC405501 (2.15)
BX599 (2.33)
BX589 (2.17)
ZC409985 (2.48)
ZC410041 (2.45)
GMASS-2303 (2.45)
GMASS-2540 (1.61)
BX455 (2.41)
BX502 (2.18)
BX513 (2.11)
1" (8kpc)
10^10
10^11
M* [M⊙]
SINS/zC-SINF
AO Survey


SFR [M⊙yr⁻¹]
1000
100
10
HST/WFC3 H-band
imaging (or ACS I band)
×10-MS
×4-MS
MS
SA12-6339 (2.30)
D3a-6397 (1.51)
ZC407302 (2.18)
ZC400569 (2.24)
BX543 (2.52)
D3a-6004 (2.39)
ZC406690 (2.20)
ZC405226 (2.29)
D3a-15504 (2.38)
BX482 (2.26)
ZC412369 (2.03)
ZC413507 (2.48)
ZC403741 (1.45)
ZC400528 (2.39)
ZC413597 (2.45)
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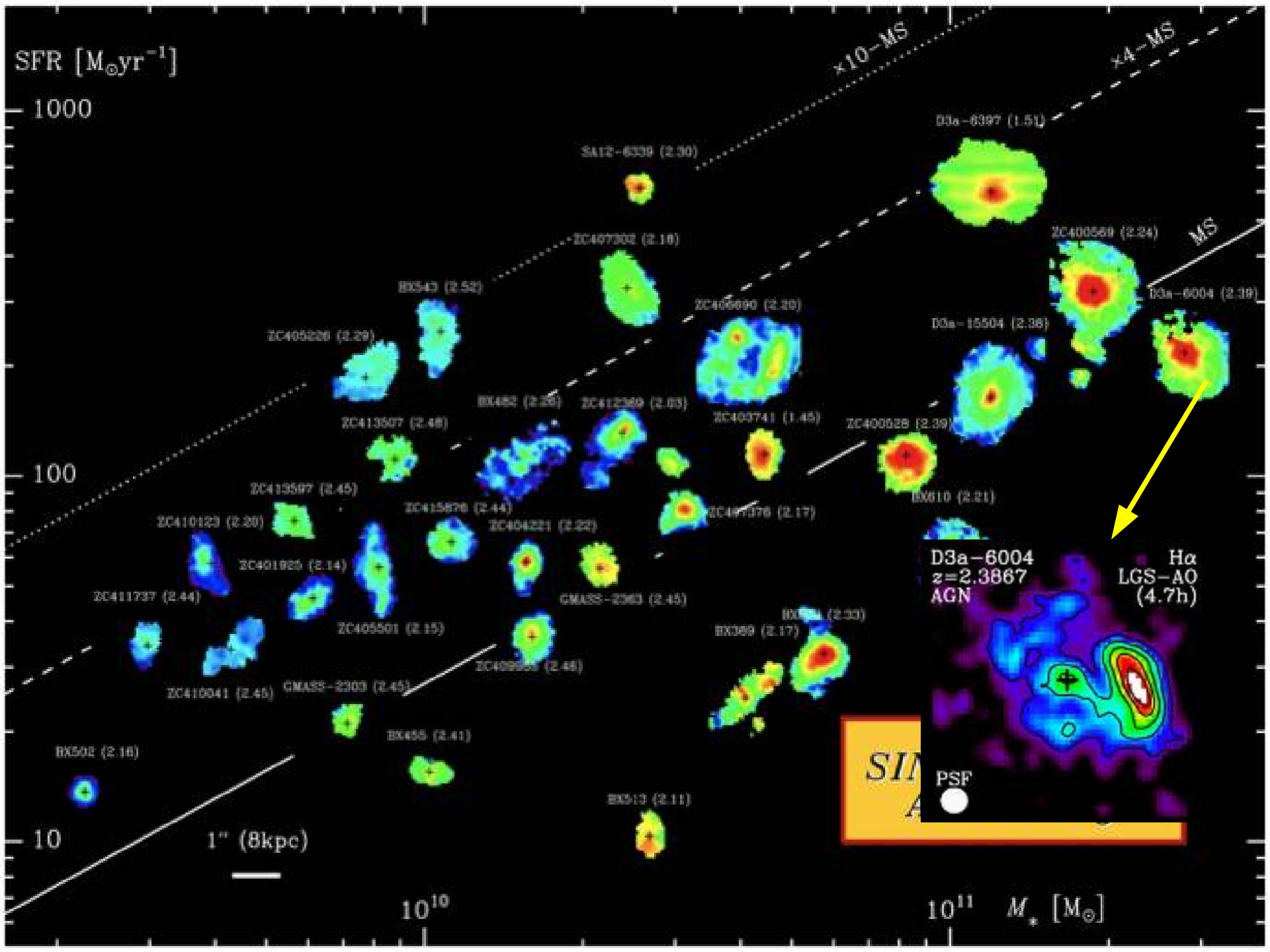
ZC401925 (2.14)
GMASS-2363 (2.45)
ZC411737 (2.44)
ZC405501 (2.15)
BX389 (2.17)
ZC410041 (2.45)
GMASS-2303 (2.45)
BX455 (2.41)
BX502 (2.16)
BX513 (2.11)
1" (8kpc)
10^10
10^11
M* [M⊙]
SINS/zC-SINF
AO Survey


SFR [M⊙yr⁻¹]
1000
100
10
×10-MS
×4-MS
MS
SA12-6339 (2.30)
D3a-6397 (1.51)
ZC407302 (2.18)
ZC400569 (2.24)
BX543 (2.52)
ZC406690 (2.20)
D3a-6004 (2.39)
ZC405226 (2.29)
D3a-15504 (2.38)
BX482 (2.26)
ZC412369 (2.03)
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ZC400528 (2.39)
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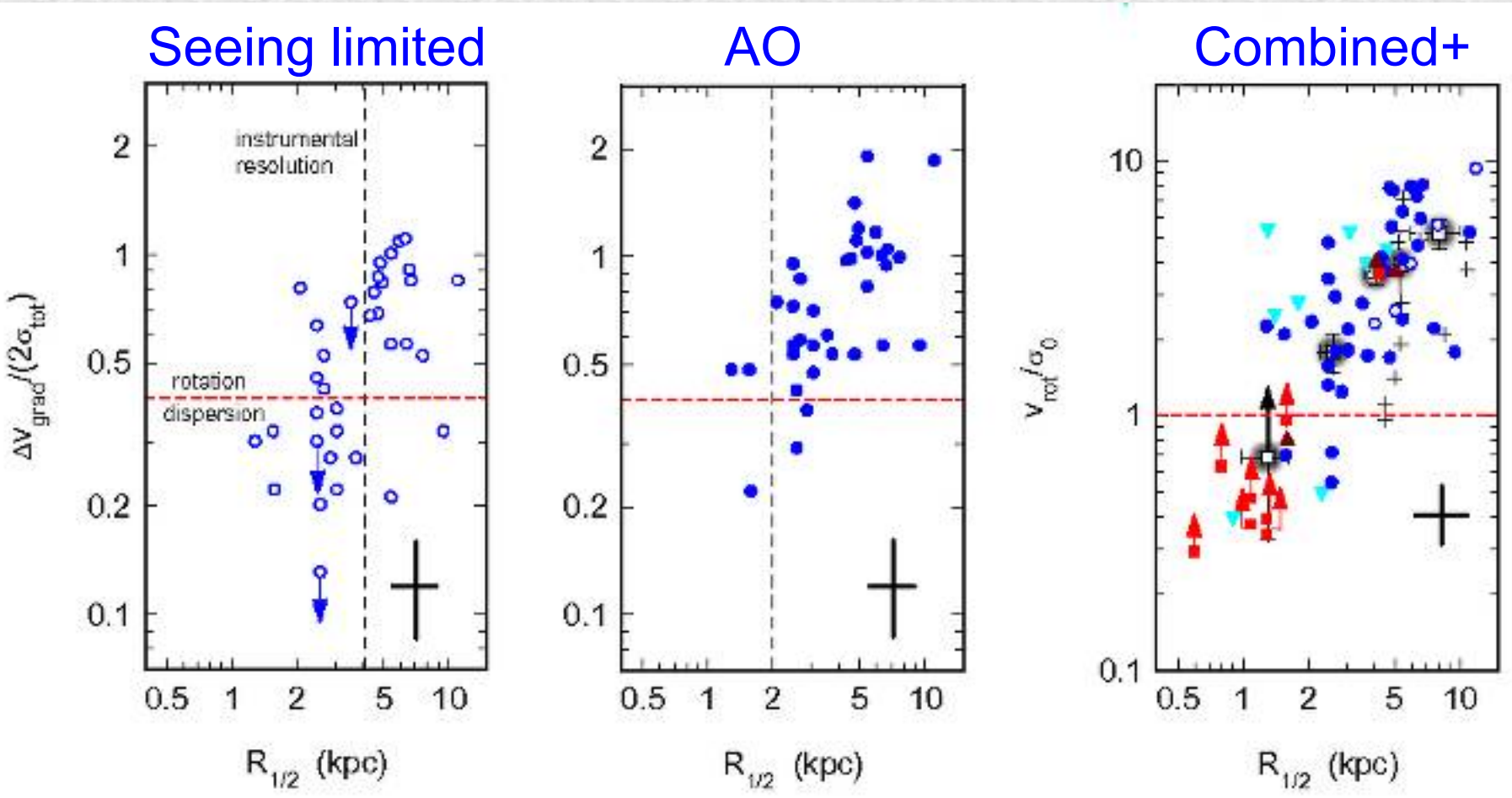
GMASS-2363 (2.45)
ZC411737 (2.44)
ZC405501 (2.15)
BX389 (2.17)
ZC410041 (2.45)
GMASS-2303 (2.45)
BX455 (2.41)
BX502 (2.16)
BX513 (2.11)
1" (8kpc)
10¹⁰
10¹¹
M* [M⊙]
D3a-6004
z=2.3867
AGN
Hα
LGS-AO
(4.7h)
PSF

Rotation vs Vel. Dispersion in Natural Seeing vs AO data



Summary

- Redshift ~2 SF galaxies come in roughly equal fractions as disks (~50%), merger-like (~25%), and compact dispersion-dominated galaxies (~25%)
- Galaxies are very gas rich, F_{gas} ~ 0.5
- Disks have high velocity dispersion (σ ~ 50-100 km/s)
- Disks are unstable to fragmentation to form clumps
- Both whole galaxies and individual clumps sustain vigorous galactic wind (mass loss rate ~ SFR)
- The "loading factor", wind mass loss rate /SFR ~ 1 and almost independent of mass

Tantalizing inferences

- We may be seeing Thick Disks in formation
- Clump migration and coalescence to the center may result in bulge formation
- Compact dispersion-dominated galaxies are more puzzling. Forming bulges that may accrete disks later?
- Galaxy evolution is controlled by gas inflows and outflows
- Several of these galaxies must soon be quenched, leading to early-type ("elliptical") galaxies.

Thank You