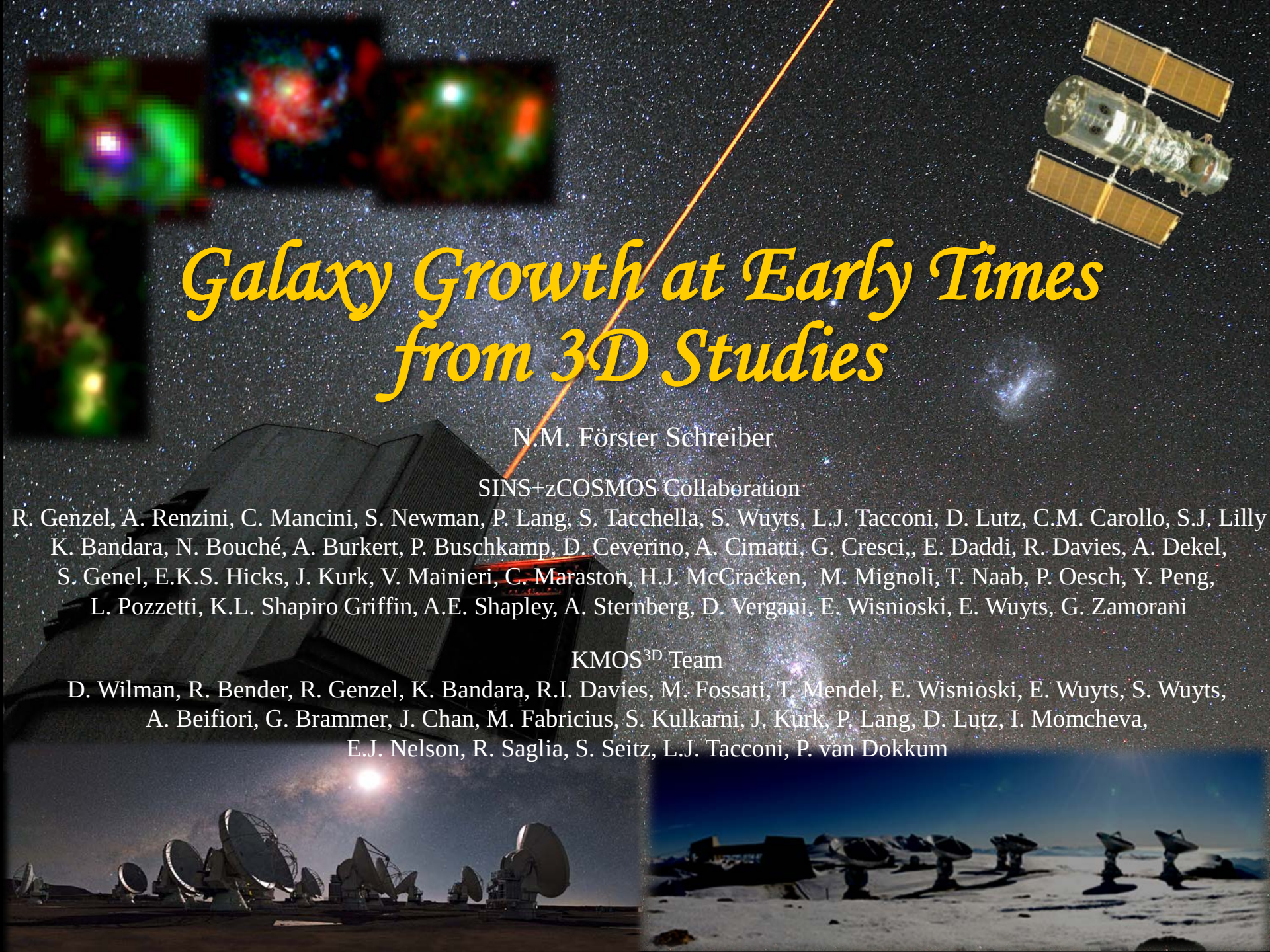


Galaxy Growth at Early Times from 3D Studies

N.M. Förster Schreiber

SINS+zCOSMOS Collaboration

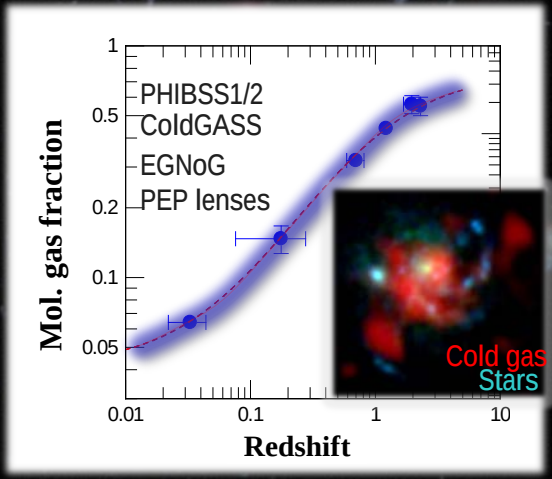
R. Genzel, A. Renzini, C. Mancini, S. Newman, P. Lang, S. Tacchella, S. Wuyts, L.J. Tacconi, D. Lutz, C.M. Carollo, S.J. Lilly
K. Bandara, N. Bouché, A. Burkert, P. Buschkamp, D. Ceverino, A. Cimatti, G. Cresci,, E. Daddi, R. Davies, A. Dekel,
S. Genel, E.K.S. Hicks, J. Kurk, V. Mainieri, C. Maraston, H.J. McCracken, M. Mignoli, T. Naab, P. Oesch, Y. Peng,
L. Pozzetti, K.L. Shapiro Griffin, A.E. Shapley, A. Sternberg, D. Vergani, E. Wisnioski, E. Wuyts, G. Zamorani

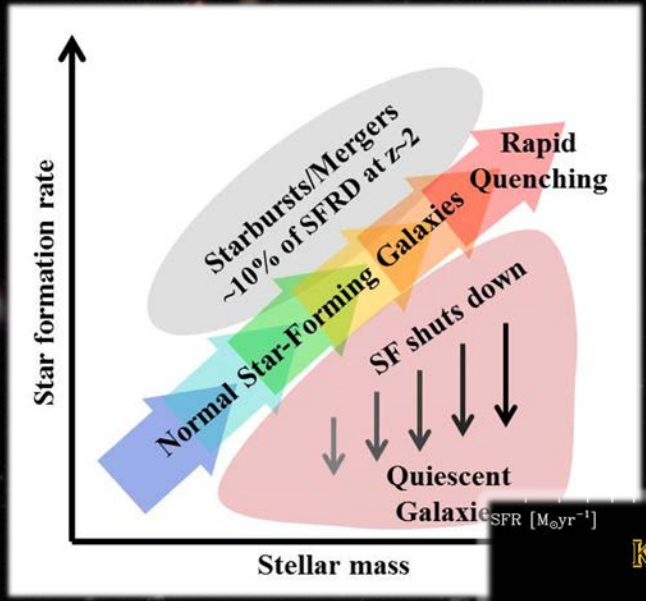
KMOS^{3D} Team

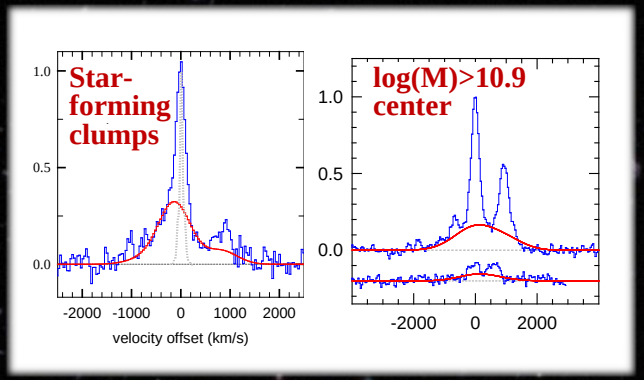
D. Wilman, R. Bender, R. Genzel, K. Bandara, R.I. Davies, M. Fossati, T. Mendel, E. Wisnioski, E. Wuyts, S. Wuyts,
A. Beifiori, G. Brammer, J. Chan, M. Fabricius, S. Kulkarni, J. Kurk, P. Lang, D. Lutz, I. Momcheva,
E.J. Nelson, R. Saglia, S. Seitz, L.J. Tacconi, P. van Dokkum

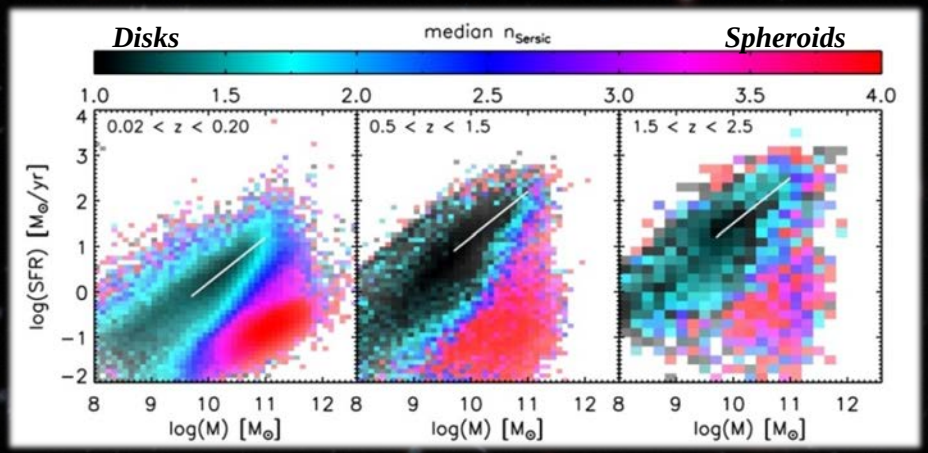
Main-Sequence of Star-forming Galaxies at z ~ 1 – 3

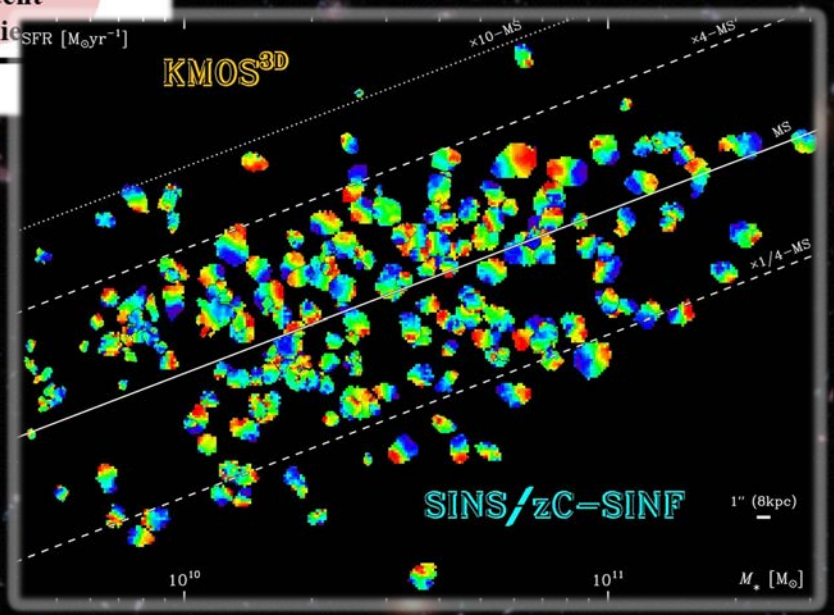
- Typically kinematic and structural gas-rich disks
- Ubiquitous powerful outflows driven by SF and AGN







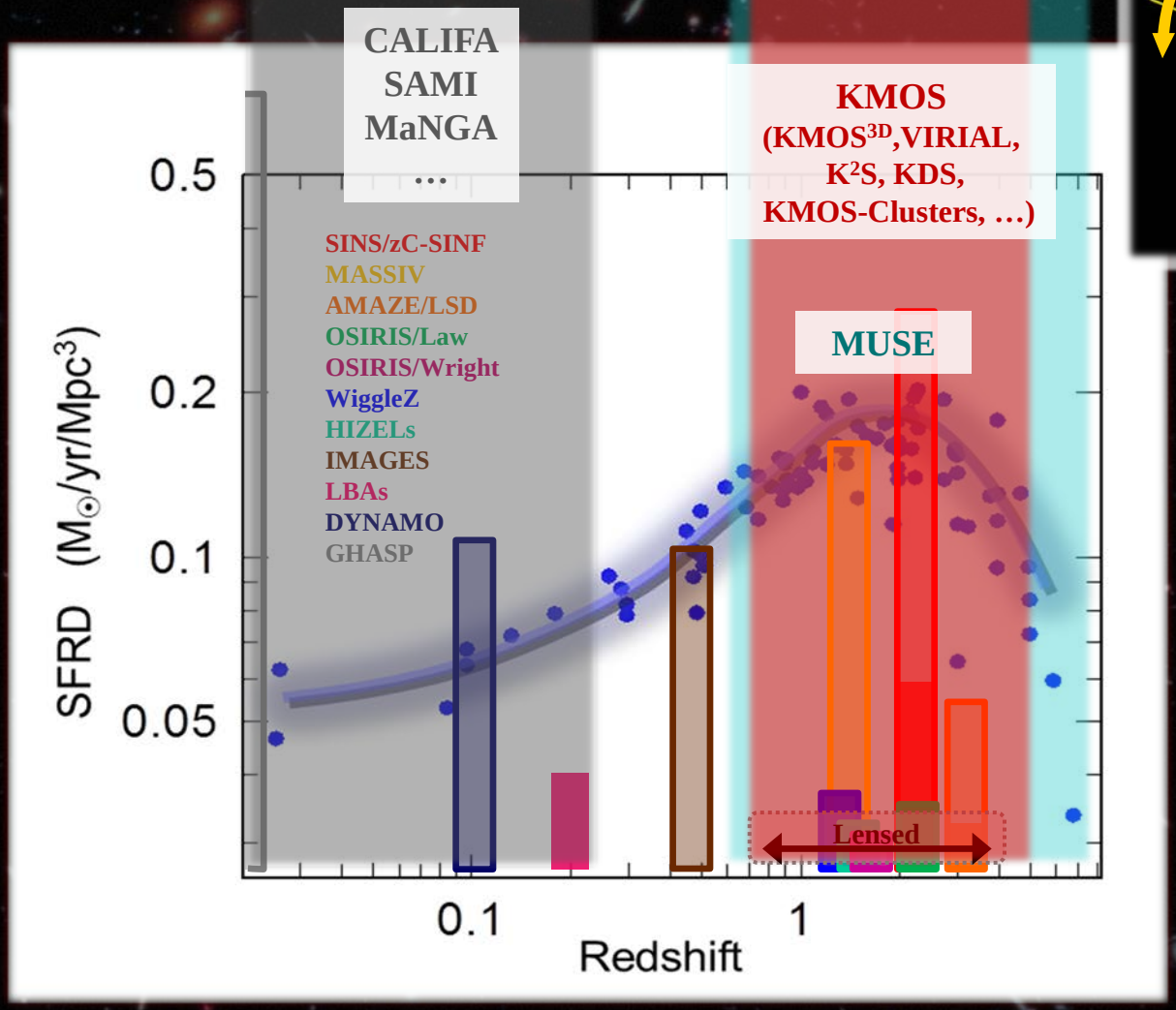


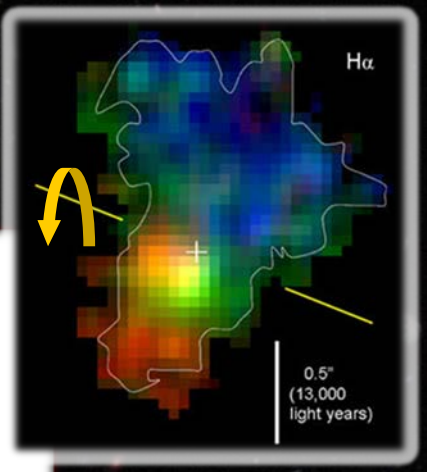


IFU Studies through Cosmic Time

≤ 2013:
~ 300 galaxies
at z ~ 1 – 4
in ~ 300 nights

≥ 2013:
~ 1000's galaxies
at z ~ 1 – 4
in ~ 300 nights

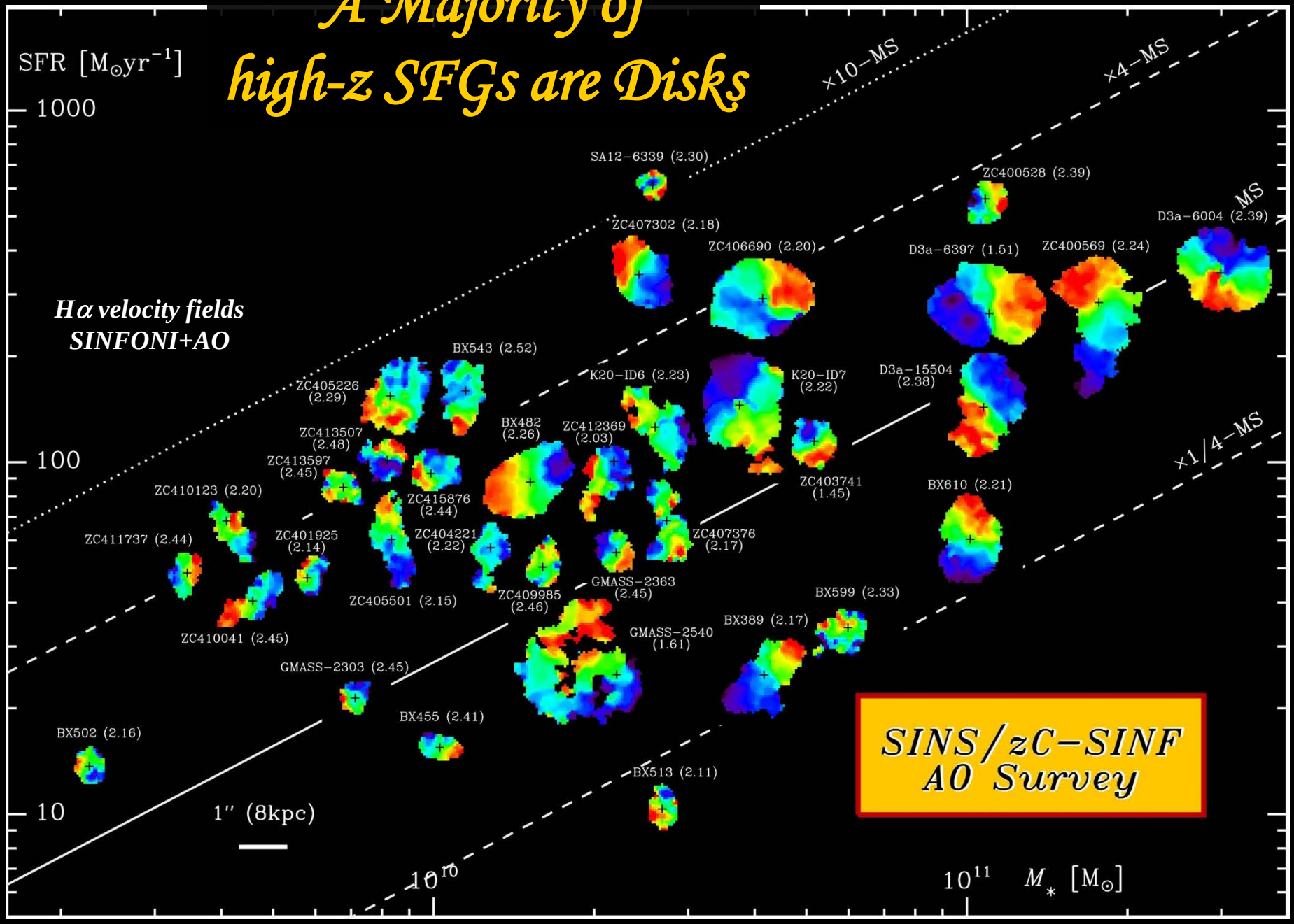




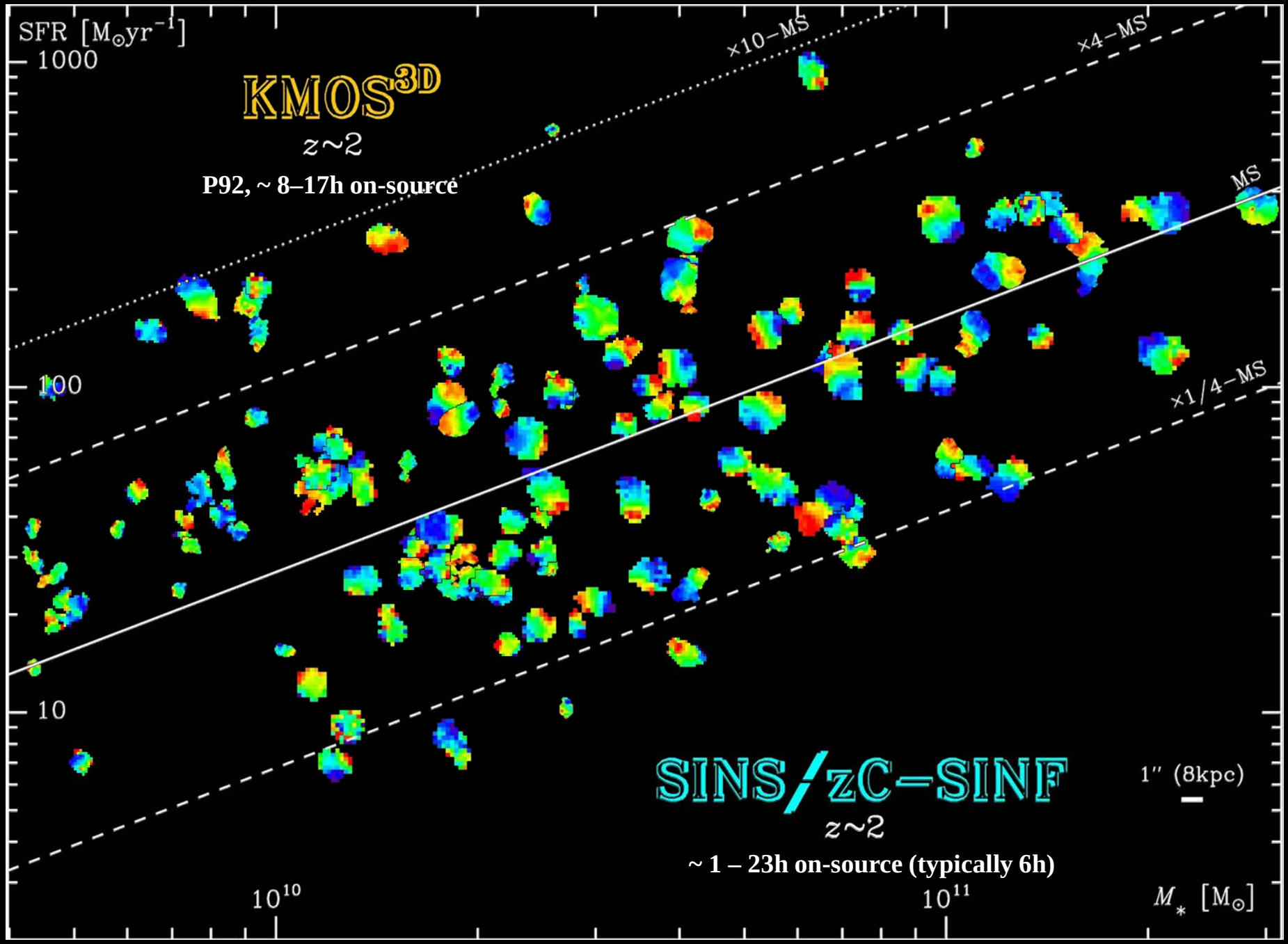
➡ **See Review by Glazebrook (2013)**

SINS/zC-SINF: NMFS+09/14,Mancini+11,Newman+13; MASSIV: Épinat+09a/12,Contini+12,Sanchez-Lopez+12; AMAZE/LSD: Gnerucci+10/11; OSIRIS: Law+09/12,Wright+09; WiggleZ: Wisnioski+11,12; HiZELs: Swinbank+12a/12b; IMAGES: Flores+06, Yang+08, Puech+12; LBAs: Basu-Zych+09, Gonçalves+10; DYNAMO: Green+10; GHASP: Épinat+09b/10
Also, Lensed objects: Stark+08, Jones+10/12, Yuan+11/12, E.Wuyts+13, Bandara+13

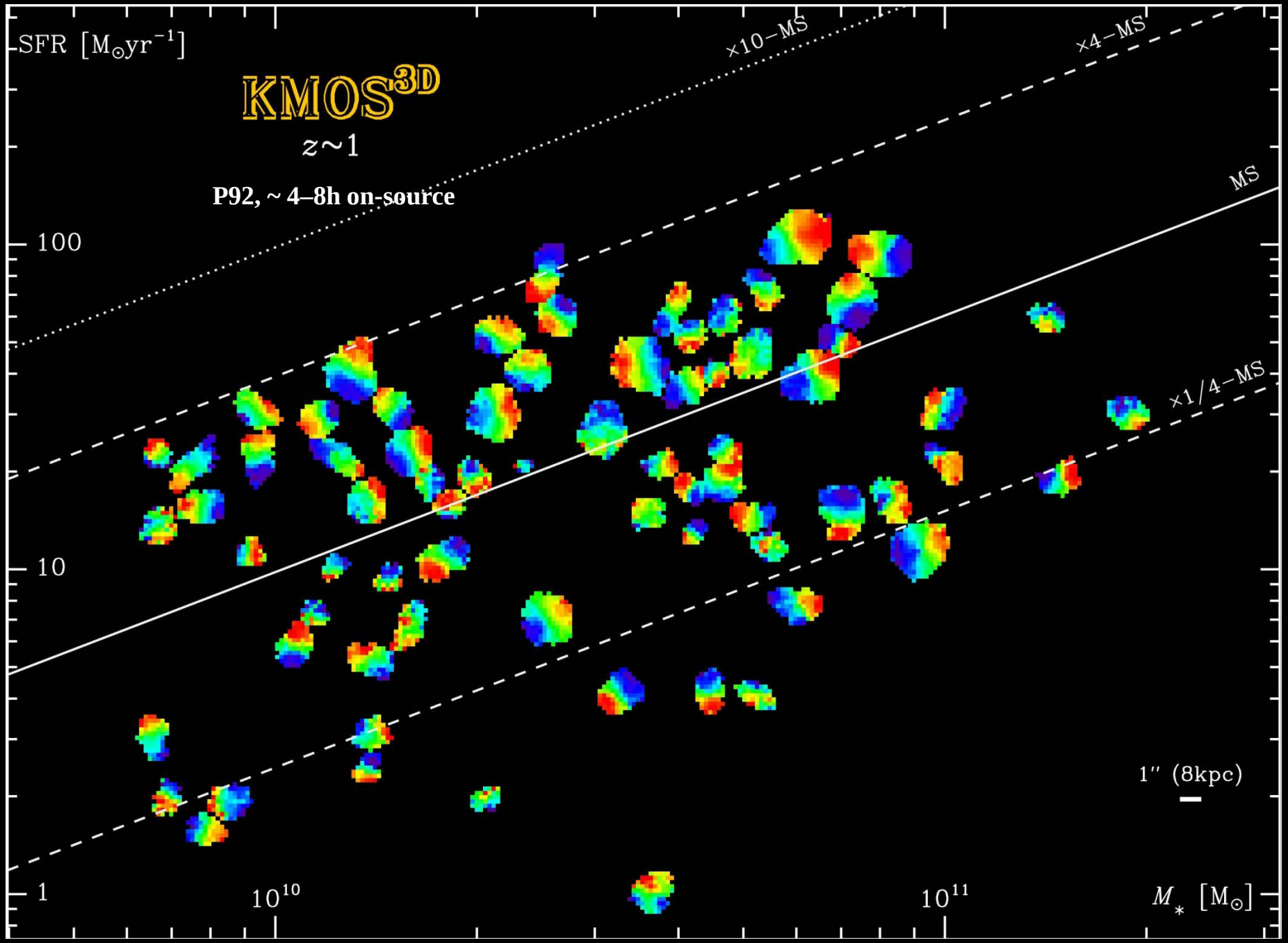
A Majority of high-z SFGs are Disks



NMFS+09; Mancini+11; NMFS/Mancini+14; among others

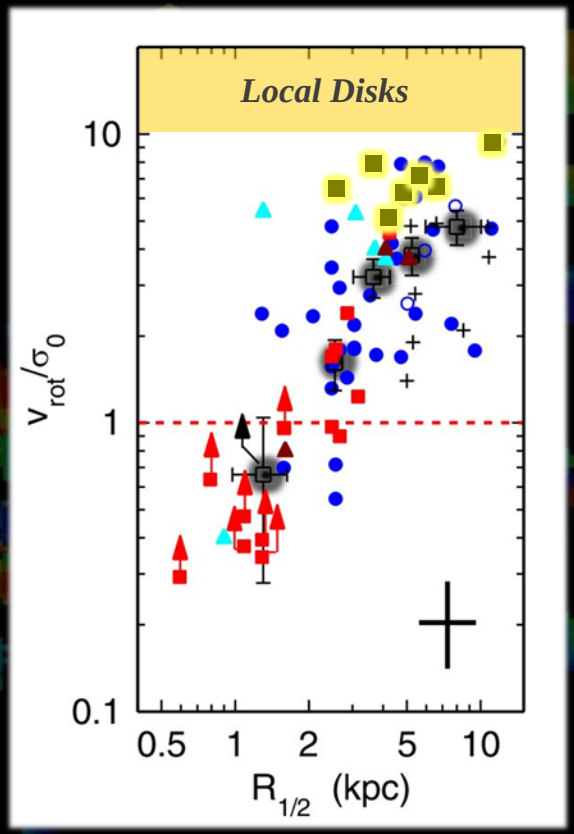


NMFS+09; Mancini+11; NMFS/Mancini+14; Wisnioski+14. Also, Stott+13; Swinbank+14; among others



NMFS+09; Mancini+11; NMFS/Mancini+14; Wisnioski+14. Also, Stott+13; Swinbank+14; and many others

High-z Disks are Turbulent



Rotation-dominated
~80%

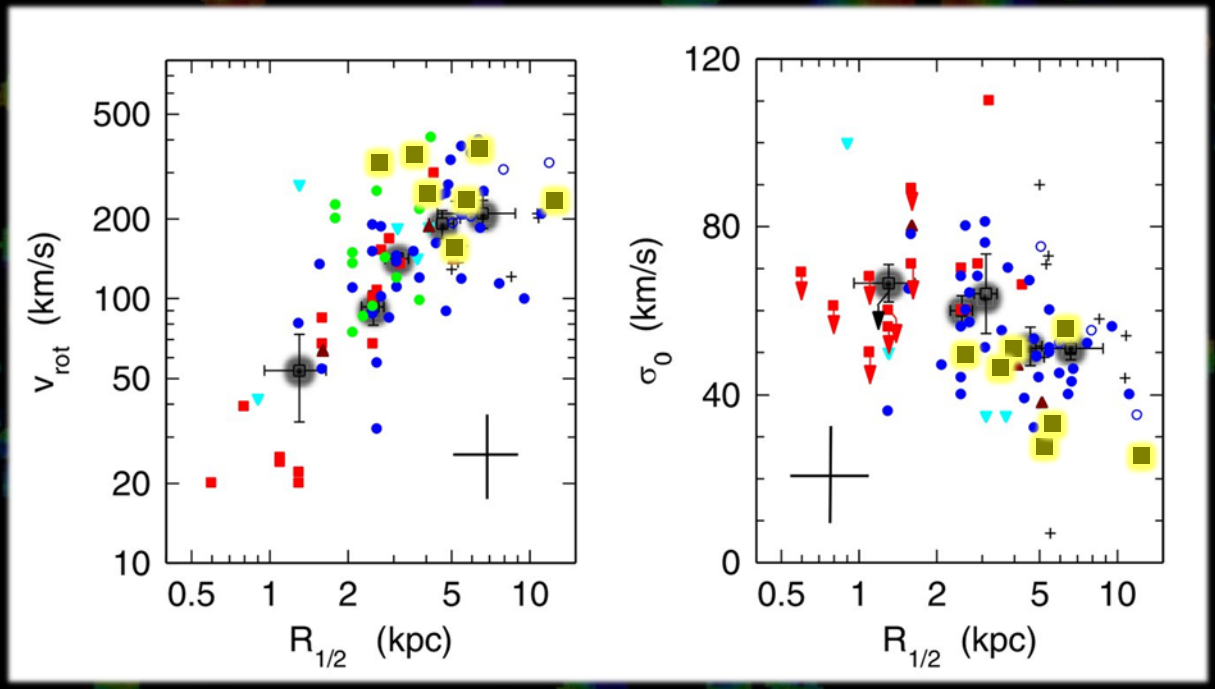
Dispersion-dominated
~20%

SINS - zC-SINF AO
SINS seeing R>4.5 kpc
Wisnioski AO
Swinbank AO
Law - Wright AO
Lemoine-Busserolle - Epinat seeing R>4.5 kpc
Epinat AO
CO

Newman+13; Wisnioski+14 ; CO: Swinbank+11,12; Tacconi+13; Genzel+13

Also: Dib+06; NMFS+06,09,14; Genzel+06,08,13; Stark+08; Cresci+09; Law+09,12; Wright+09; Épinat+09a,09b,12; Lehnert+09,13; Jones+10; Green+10; Gnerucci+10; Swinbank+12; Kassin+12; Lemoine-Busserolle+12; Newman+13

High-z Disks are Turbulent

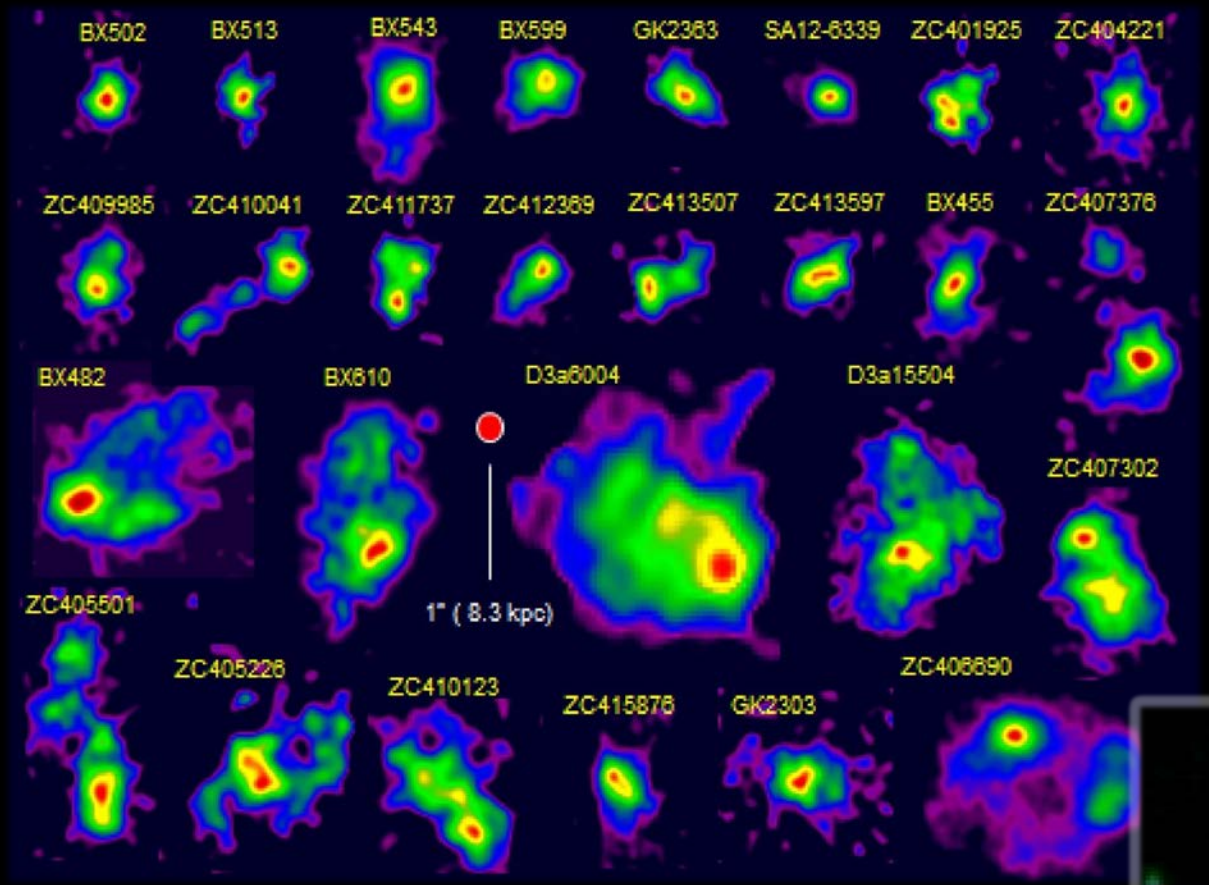


SINS - zC-SINF AO
SINS seeing R>4.5 kpc
Wisnioski AO
Swinbank AO
Law - Wright AO
Lemoine-Busserolle - Epinat seeing R>4.5 kpc
Epinat AO
CO

Newman+13; Wisnioski+14 ; CO: Swinbank+11,12; Tacconi+13; Genzel+13

Also: Dib+06; NMFS+06,09,14; Genzel+06,08,13; Stark+08; Cresci+09; Law+09,12; Wright+09; Épinat+09a,09b,12; Lehnert+09,13; Jones+10; Green+10; Gnerucci+10; Swinbank+12; Kassin+12; Lemoine-Busserolle+12; Newman+13

Clumpy Star Formation in Turbulent Gas-Rich Disks

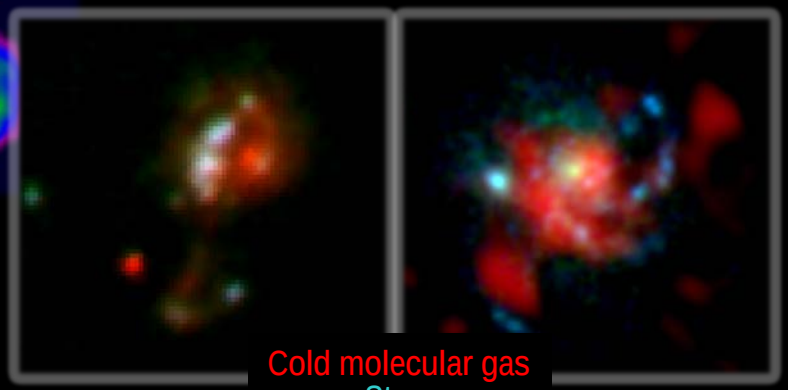


Newman+13

z ~ 2 disks:

$$L_{Toomre} \sim f_{gas} R_{disk} \sim 1 \text{ kpc}$$

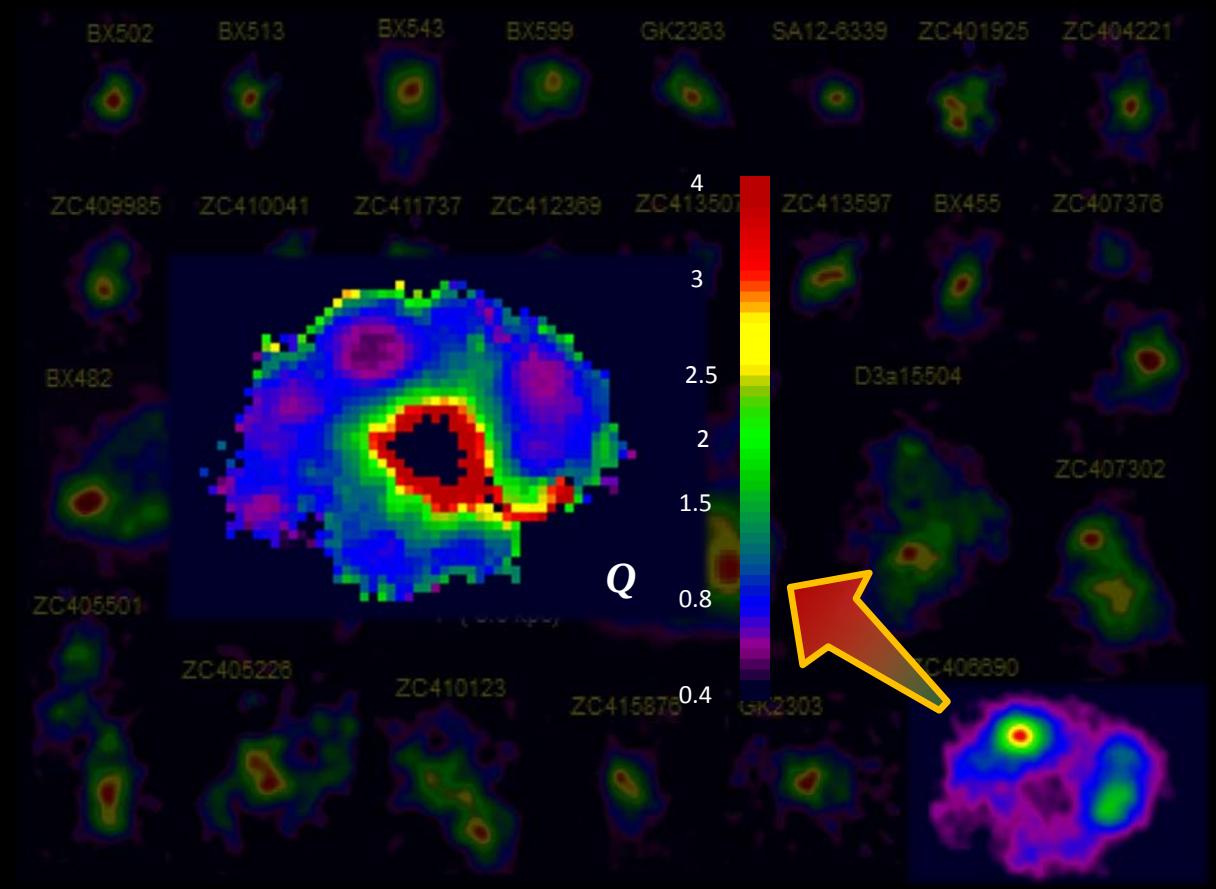
$$M_{Toomre} \sim f_{gas}^2 M_{disk} \sim 10^9 \, M_\odot$$



Tacconi+10,13

Genzel+08,11; NMFS+11b; Newman+12a; Wisnioski+12; Wuyts+13
See also, e.g., Cowie+95; Colley+96; Giavalisco+96; Elmegreen+04–09;
Lotz+04; Conselice+04; Law+07; Swinbank+10-12; Jones+10; Guo+12; Tadaki+14

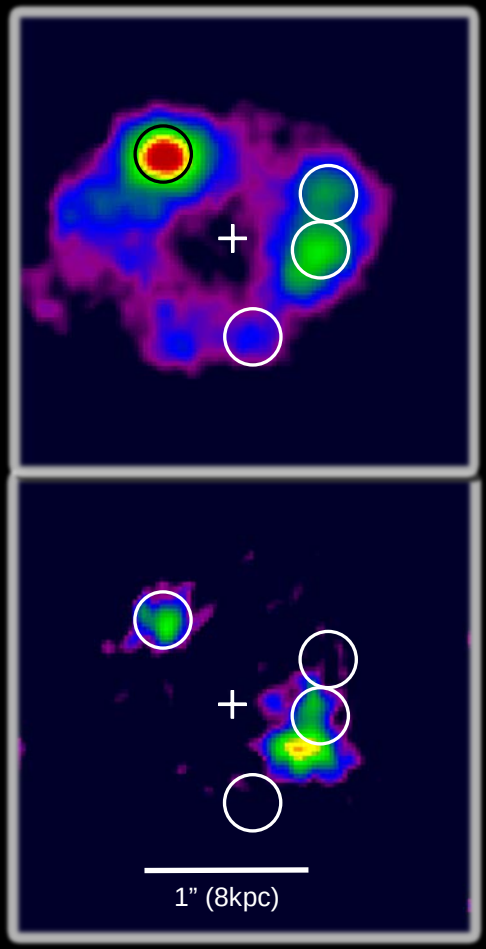
Clumpy Star Formation in Turbulent Gas-Rich Disks

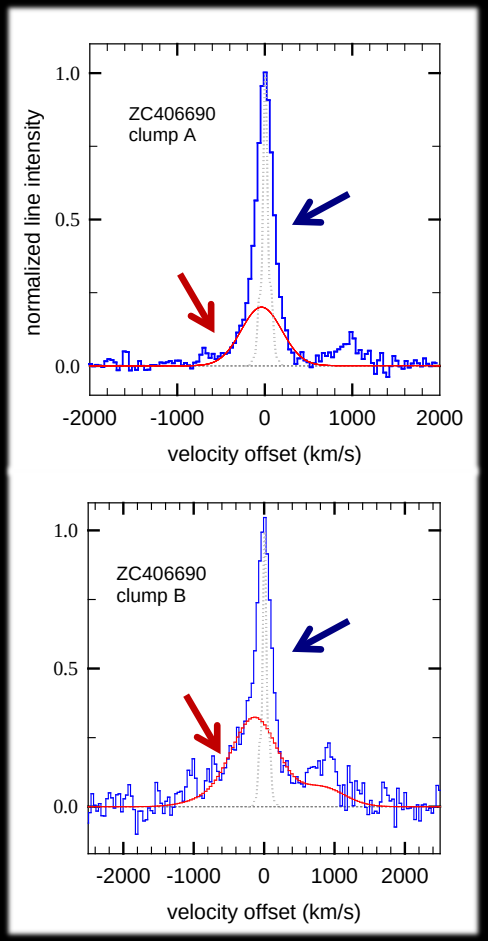


Q =

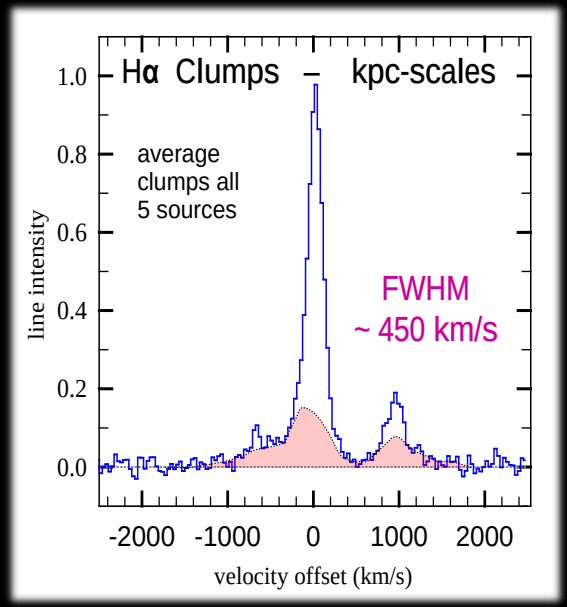
Genzel+08,11; NMFS+11b; Newman+12a; Wisnioski+12; Wuyts+13
See also, e.g., Cowie+95; Colley+96; Giavalisco+96; Elmegreen+04–09;
Lotz+04; Conselice+04; Law+07; Swinbank+10-12; Jones+10; Guo+12; Tadaki+14

Vigorous Feedback from Star Formation at z ~ 2





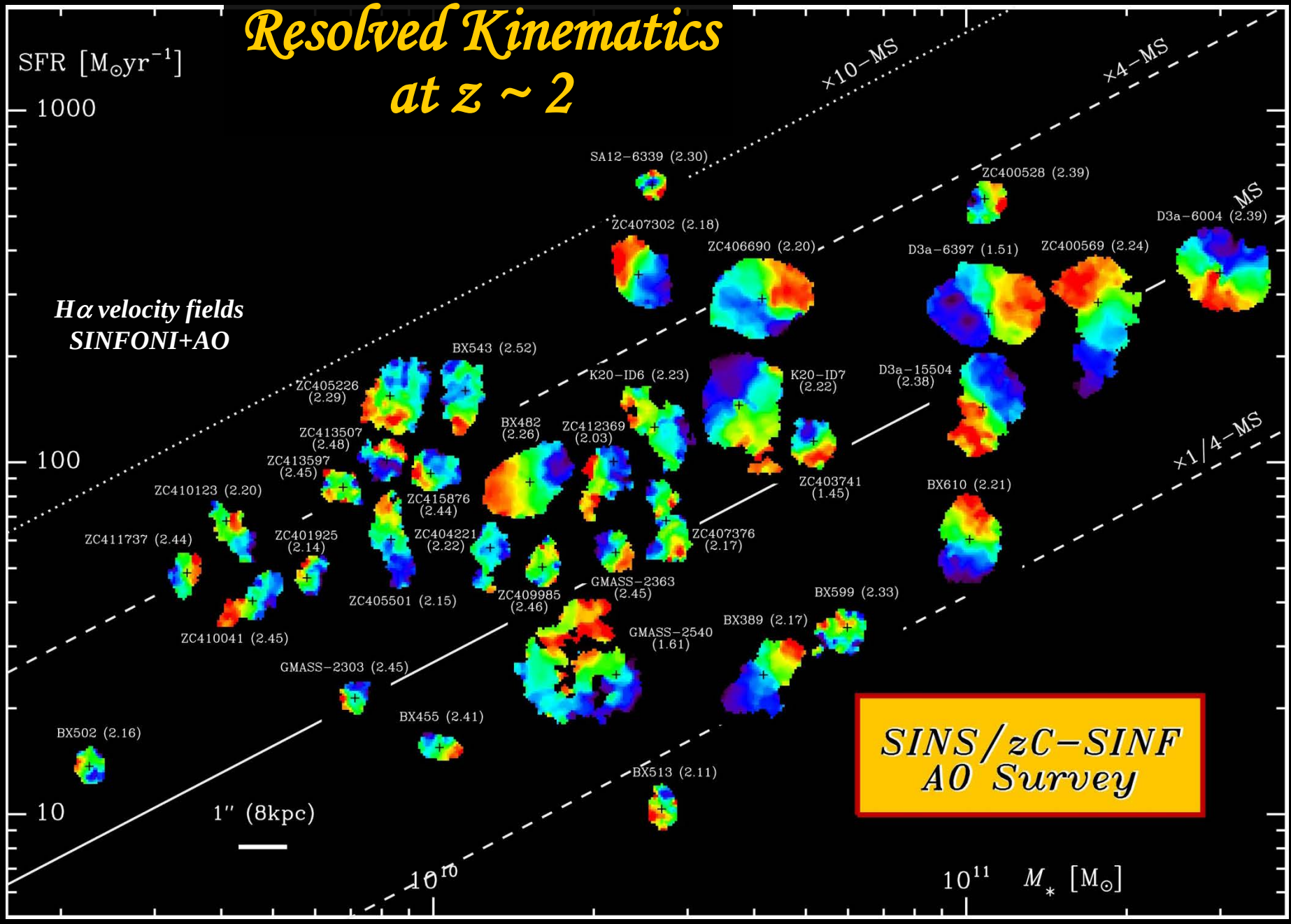
- ***Mass outflow rates in ionized gas ~ 1 – 5× SFRs***
- ***Clump lifetimes < a few 100 Myrs***



Genzel+11; Newman+12a,b; *Shapiro+09*

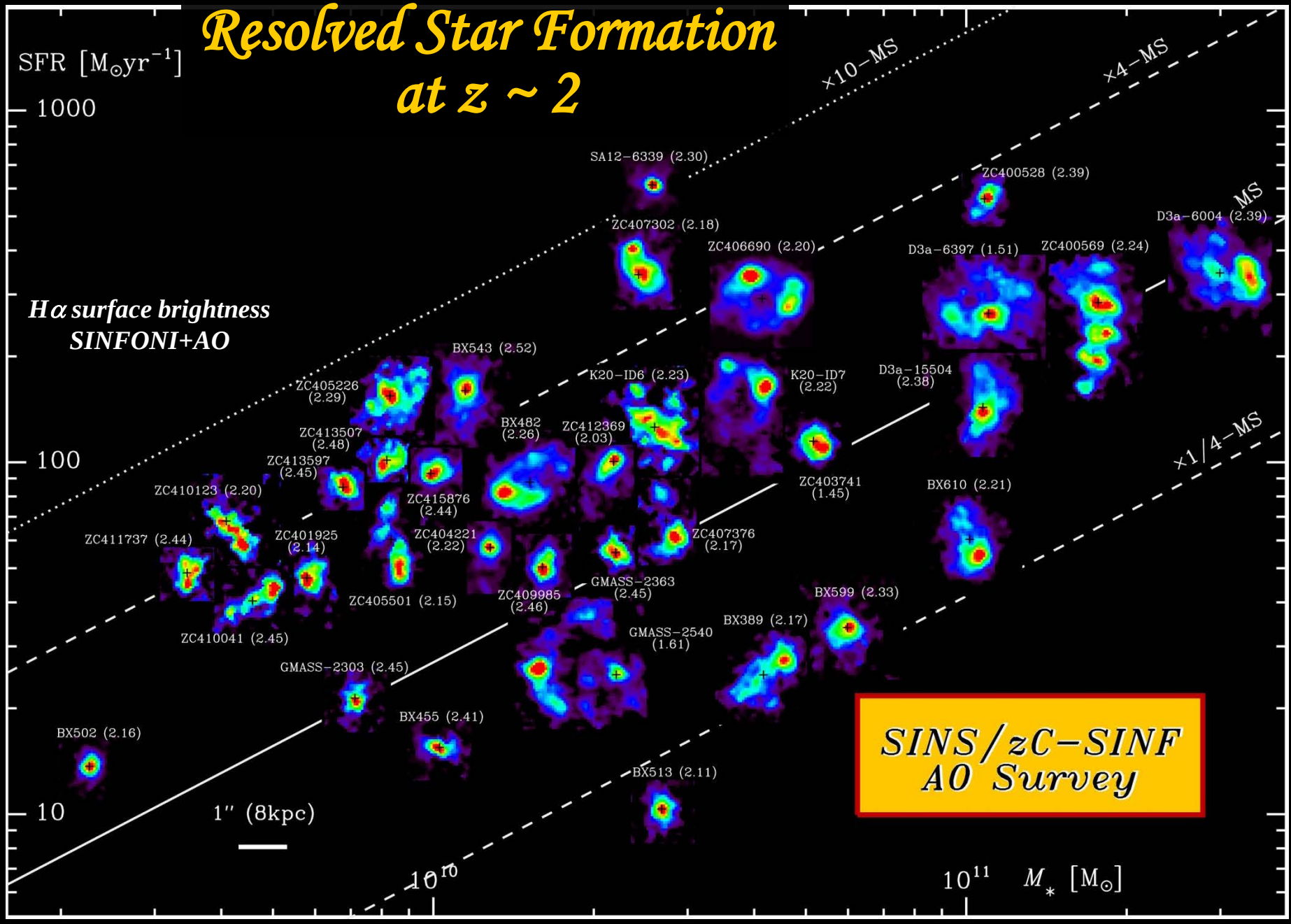
Also, Pettini+00; Shapley+03; Weiner+09; Steidel+10; Coil+11; Kulas+11; Law+12b; Kornei+12; Heckman+00; Martin+05; Rupke+02–13; Sharp,Bland-Hawthorn10; Sturm+11; Westmoquette+12,13; Rodríguez Zaurín+13; Cicone+14; and many others

Resolved Kinematics at z ~ 2



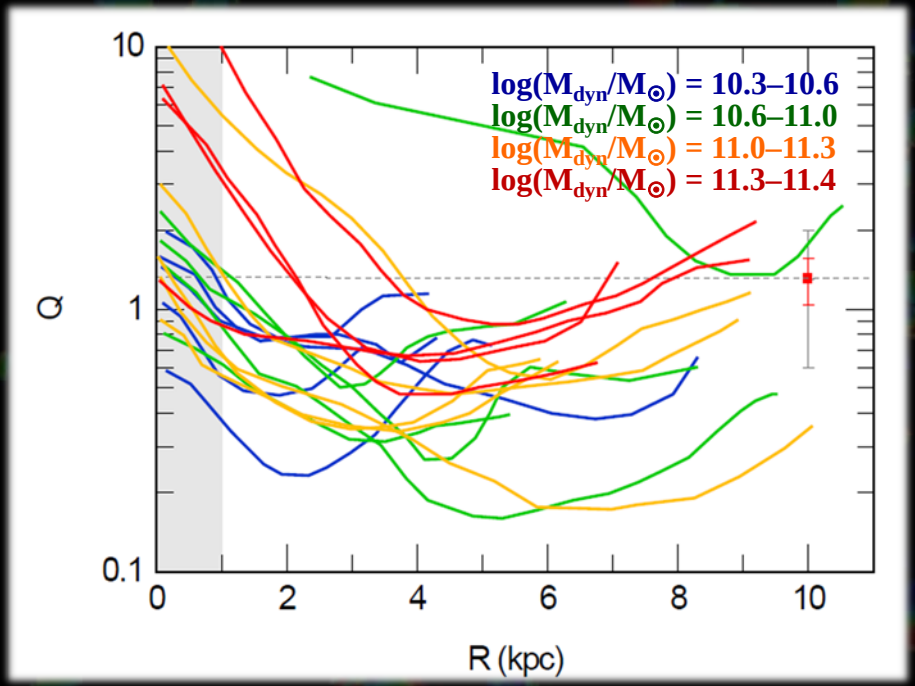
NMFS+09; Mancini+11; NMFS/Mancini+14

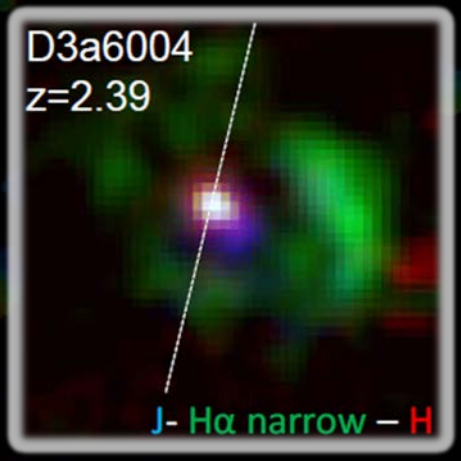
Resolved Star Formation at z ~ 2

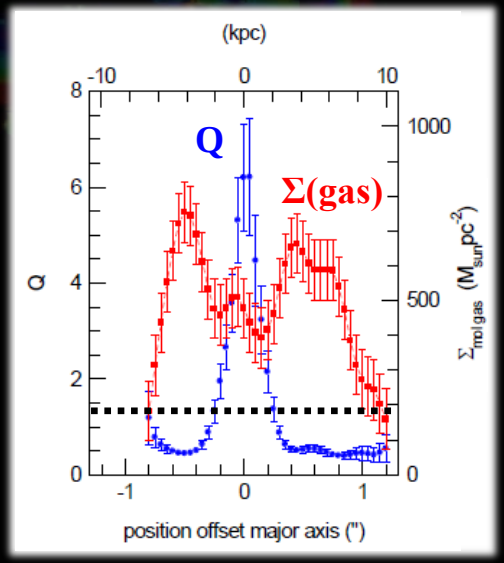


Genzel+08; NMFS+09,14; Tacchella+14; Genzel+14. Also, e.g., Swinbank+11,12; Nelson+12,13; Wuyts+13; Tadaki+14

Evidence for Gravitational Quenching





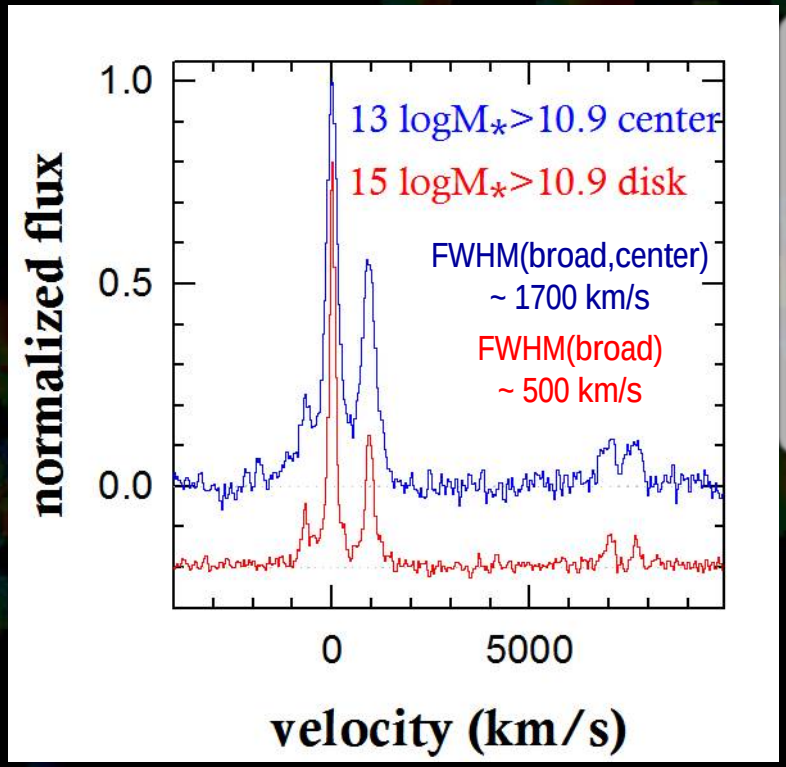


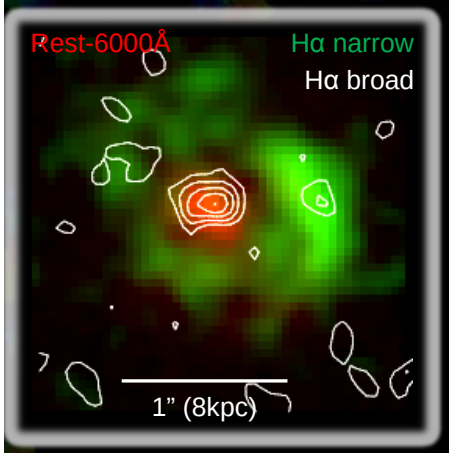
Genzel+14a

Also, e.g., Hunter+98; Martig+09,13; Saintonge+12; Crocker+12; Dekel&Burkert13

Nuclear AGN-driven Outflows in Massive z~1–2 MS SFGs

Occurrence rate
75% at log(M)>10.9





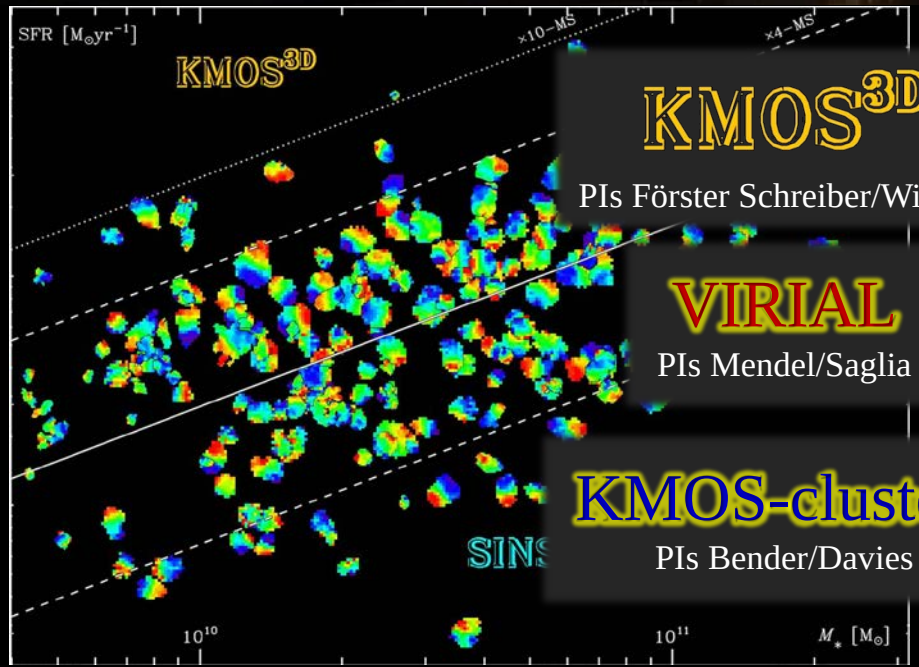
NMFS+14a; Genzel14b

Review by Fabian (2012); E.g., Nesvadba+11; Maiolino+12; Harrison+12; Diamond-Stanic+12; Cano Díaz+12; Bradshaw+13; Cecil+90; Sturm+11; Rupke,Veilleux11,13; Westmoquette+12; Cicone+12,14; Mullaney+13; Veilleux+13; Rodriguez-Zaurín+13

Future Prospects

More complete and coherent picture over cosmic time
combining detailed and global properties of galaxies

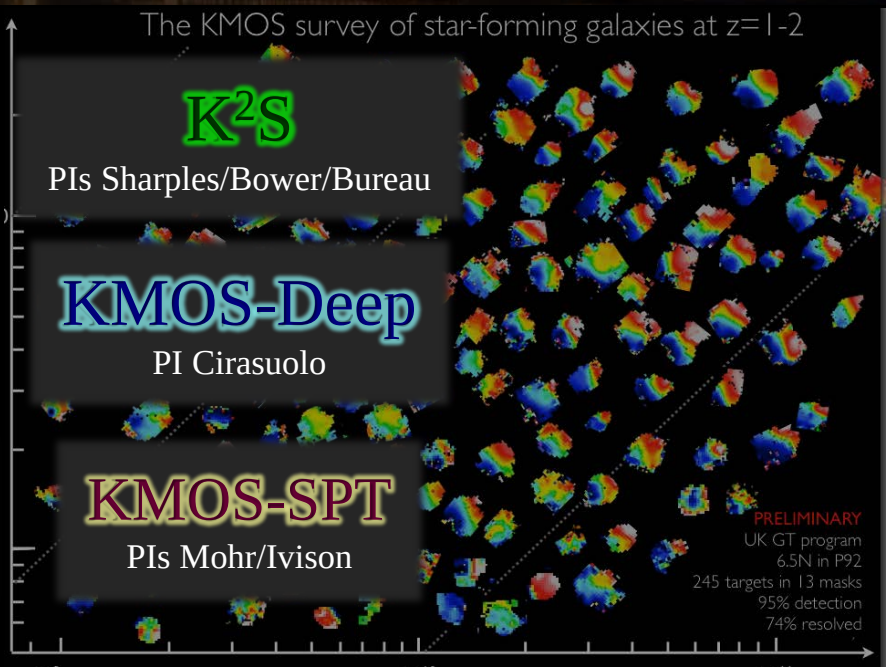
➔ ***Surveys of ~ 1000's galaxies with multi-IFUs and MOS (e.g., KMOS, MUSE, MOSFIRE)***
➔ ***Surveys of ~ 100+ with IRAM/NOEMA and ALMA***
➔ ***Synergies w/ HST, AO, and local surveys (CALIFA, SAMI, MANGA, …)***



KMOS^{3D}
PIs Förster Schreiber/Wilman

VIRIAL
PIs Mendel/Saglia

KMOS-clusters
PIs Bender/Davies



K^{2}S
PIs Sharples/Bower/Bureau

KMOS-Deep
PI Cirasuolo

KMOS-SPT
PIs Mohr/Ivison