High-z Galaxy Kinematics and Star Formation

Erin K. S. Hicks

Max Planck Institut für extraterrestrische Physik

The Team & Collaborations

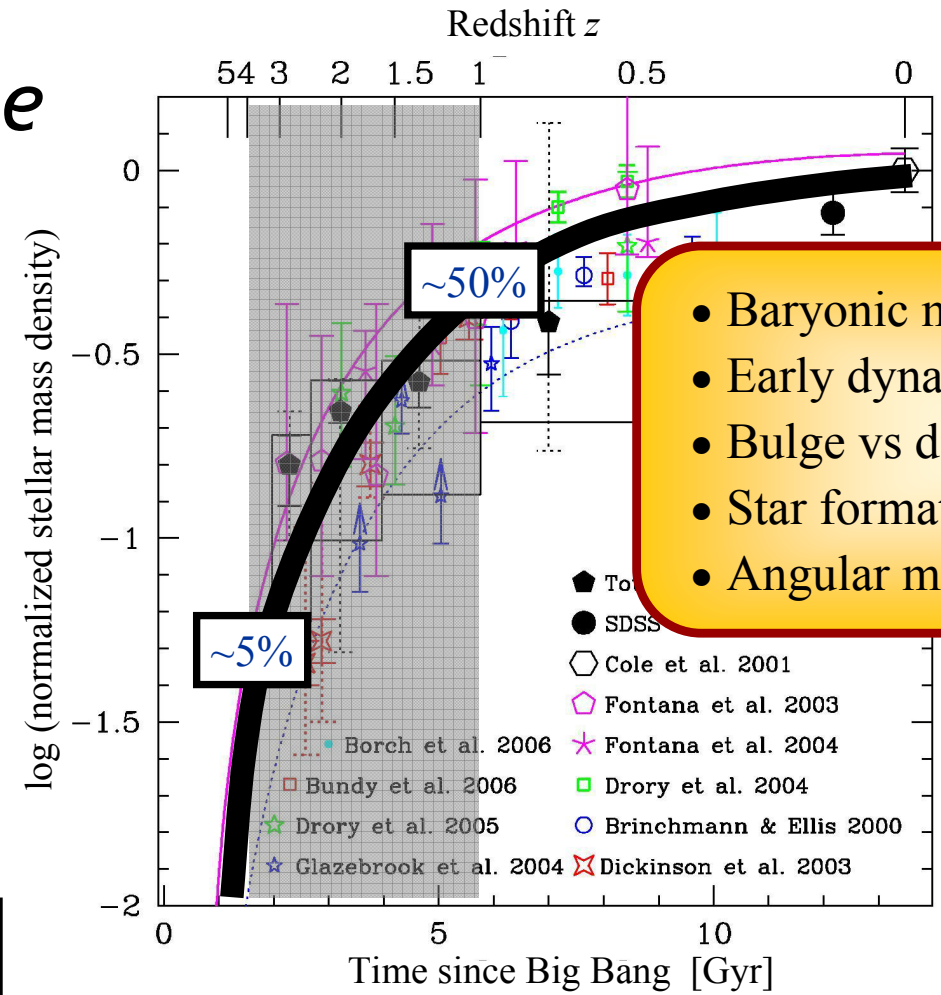
N. M. Förster Schreiber, R. Genzel, E. K. S. Hicks,
G. Cresci, R. Davies, K. Shapiro, N. Bouché, L.J. Tacconi,
D. Lutz, P. Buschkamp, S. Genel, A. Sternberg, F. Eisenhauer,
S. Gillessen, A. Verma, R. Abuter, R. Bender, S. Seitz
MPE/Berkeley/Tel Aviv/Oxford/USM

A. E. Shapley, D. K. Erb, C. C. Steidel
UCLA/CfA/Caltech

A. Renzini, S. Lilly, A. Cimatti, E. Daddi, J. Kurk, X. Kong,
& zCOSMOS, GMASS, Deep3a Teams
Padova/ETH Zürich/Bologna/CEA Saclay/MPIA/Hefei China/NAO Japan

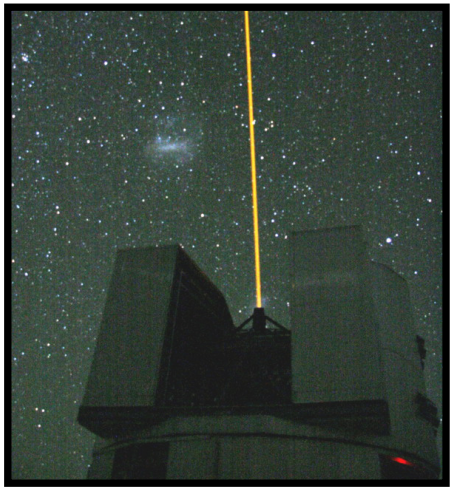
A. Burkert, T. Naab, P. Johansson
USM

Key Science Goals

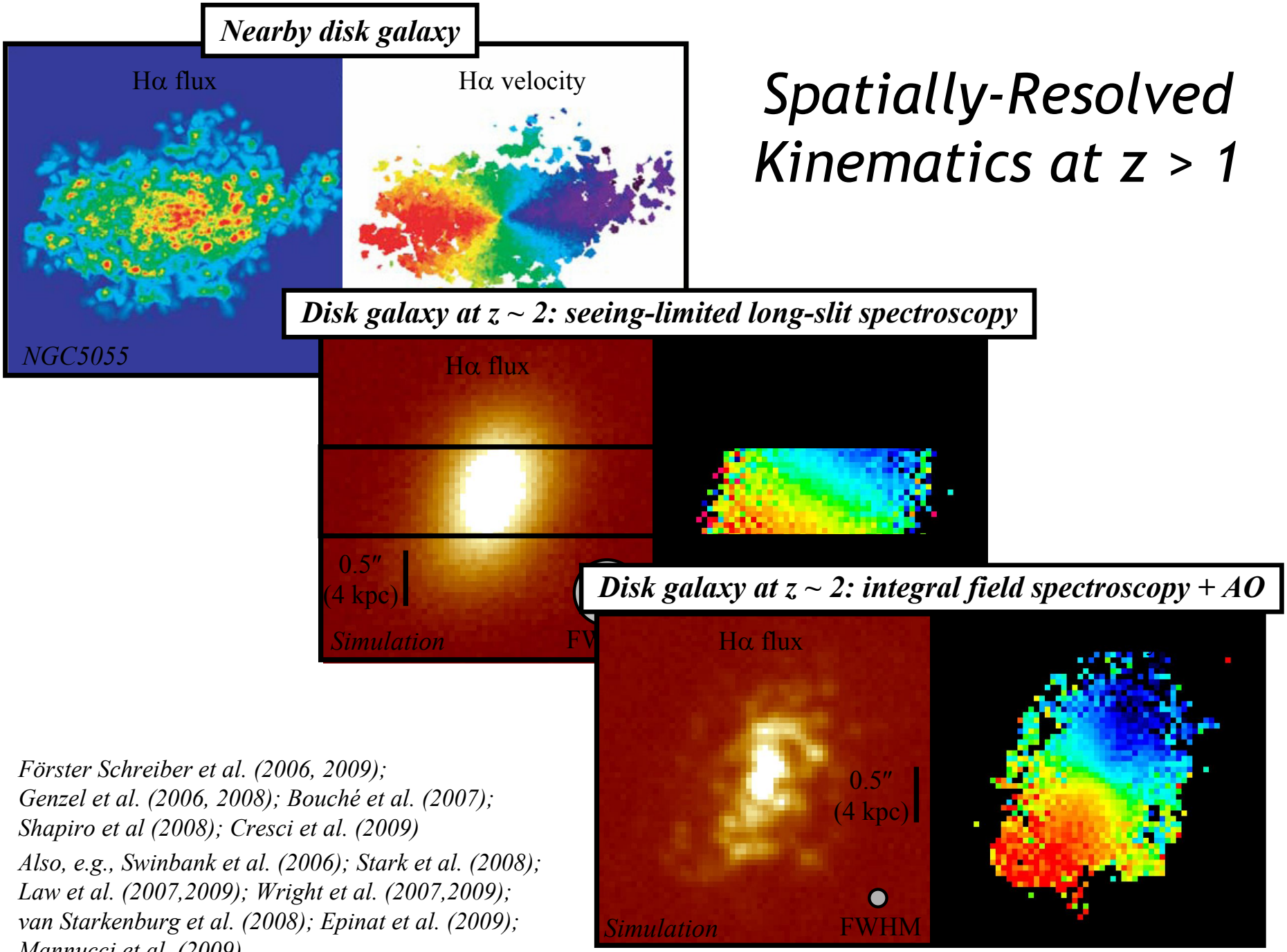


- Baryonic mass accretion?
- Early dynamical evolution?
- Bulge vs disk formation?
- Star formation and timescales?
- Angular momentum?

Rudnick et al. (2006)

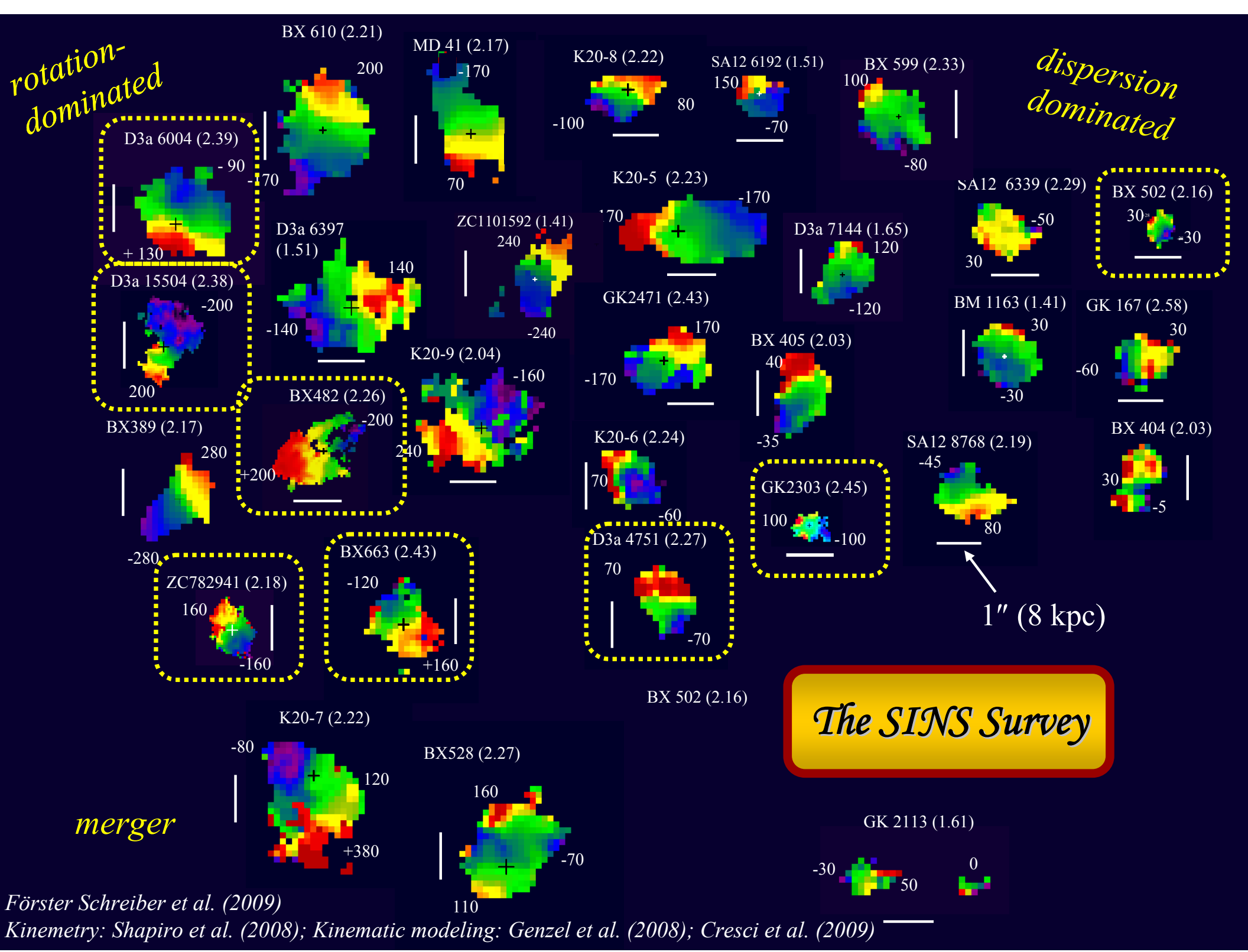


Spatially-Resolved Kinematics at z > 1



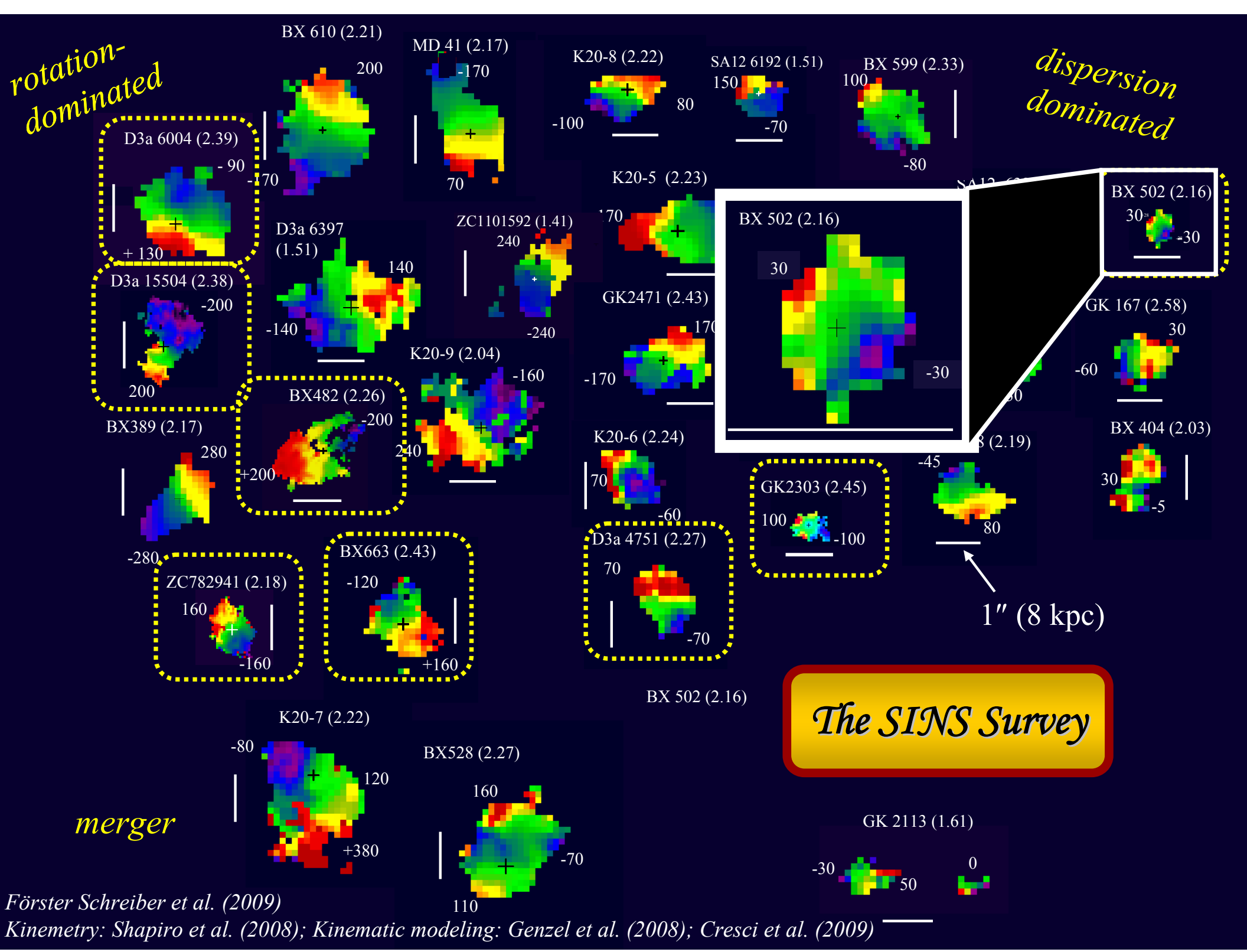
Förster Schreiber et al. (2006, 2009); Genzel et al. (2006, 2008); Bouché et al. (2007); Shapiro et al (2008); Cresci et al. (2009)

Also, e.g., Swinbank et al. (2006); Stark et al. (2008); Law et al. (2007,2009); Wright et al. (2007,2009); van Starkenburg et al. (2008); Epinat et al. (2009); Mannucci et al. (2009)

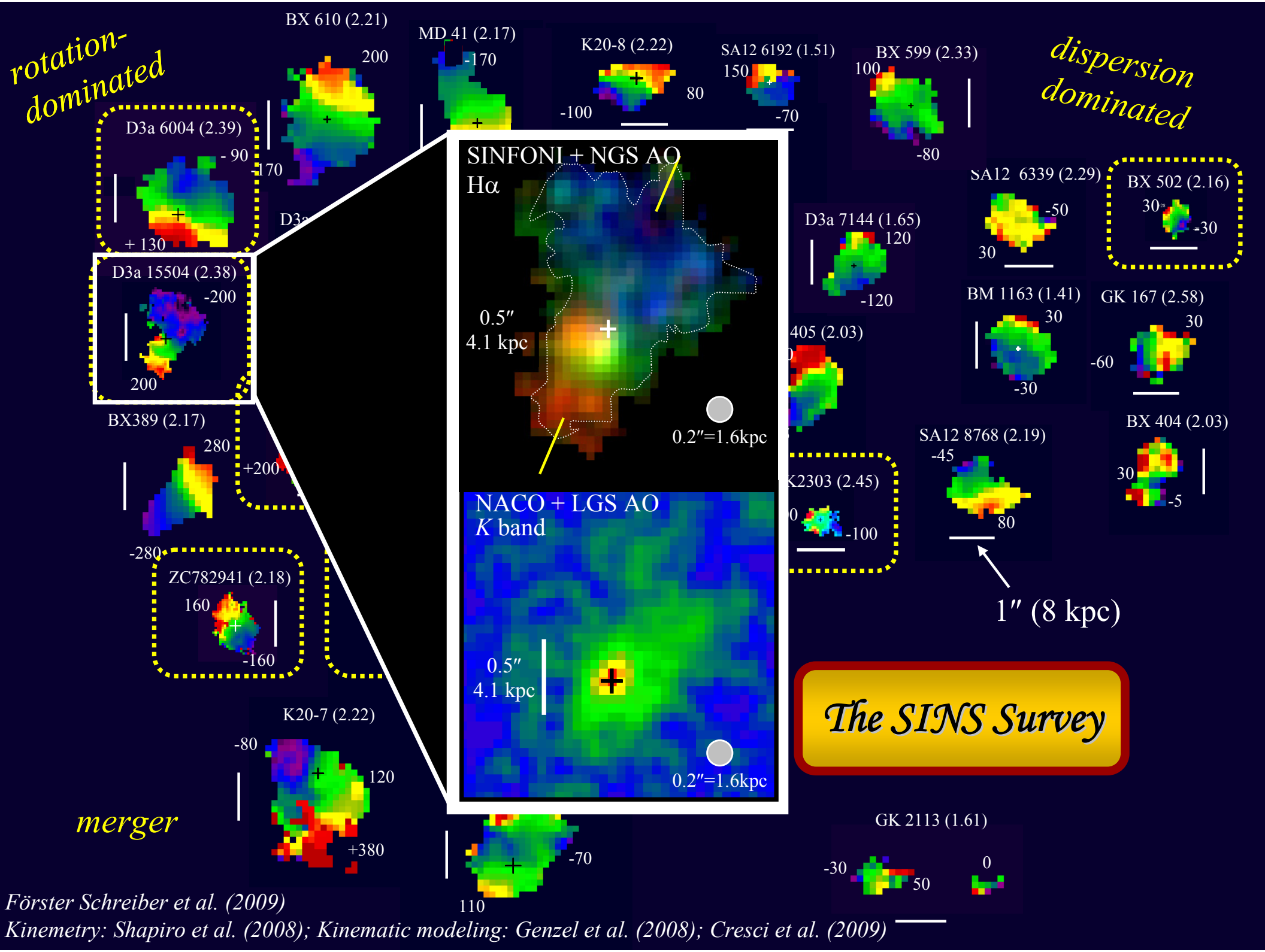


Förster Schreiber et al. (2009)

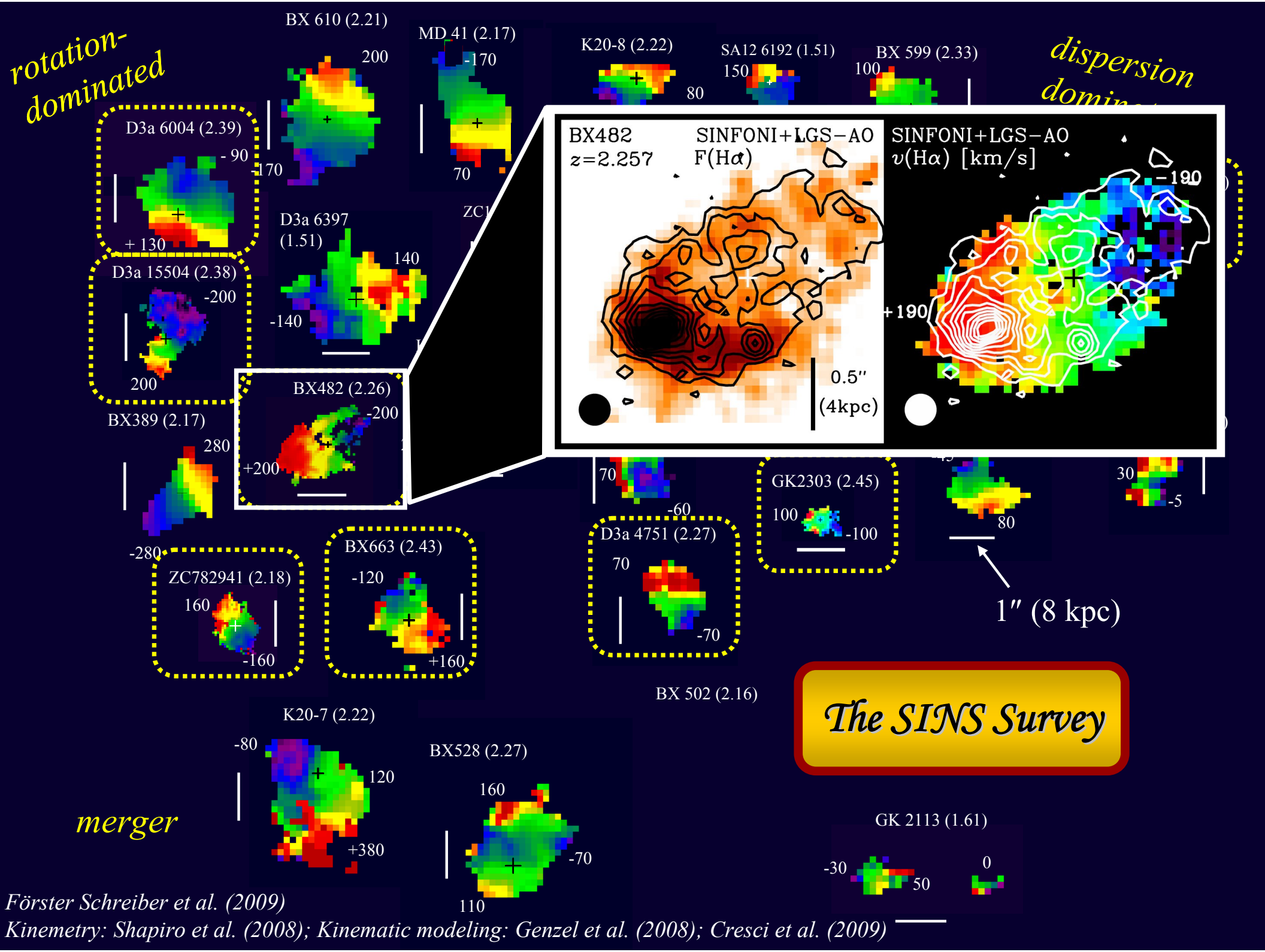
Kinemetry: Shapiro et al. (2008); Kinematic modeling: Genzel et al. (2008); Cresci et al. (2009)



Förster Schreiber et al. (2009)
Kinemetry: Shapiro et al. (2008); Kinematic modeling: Genzel et al. (2008); Cresci et al. (2009)

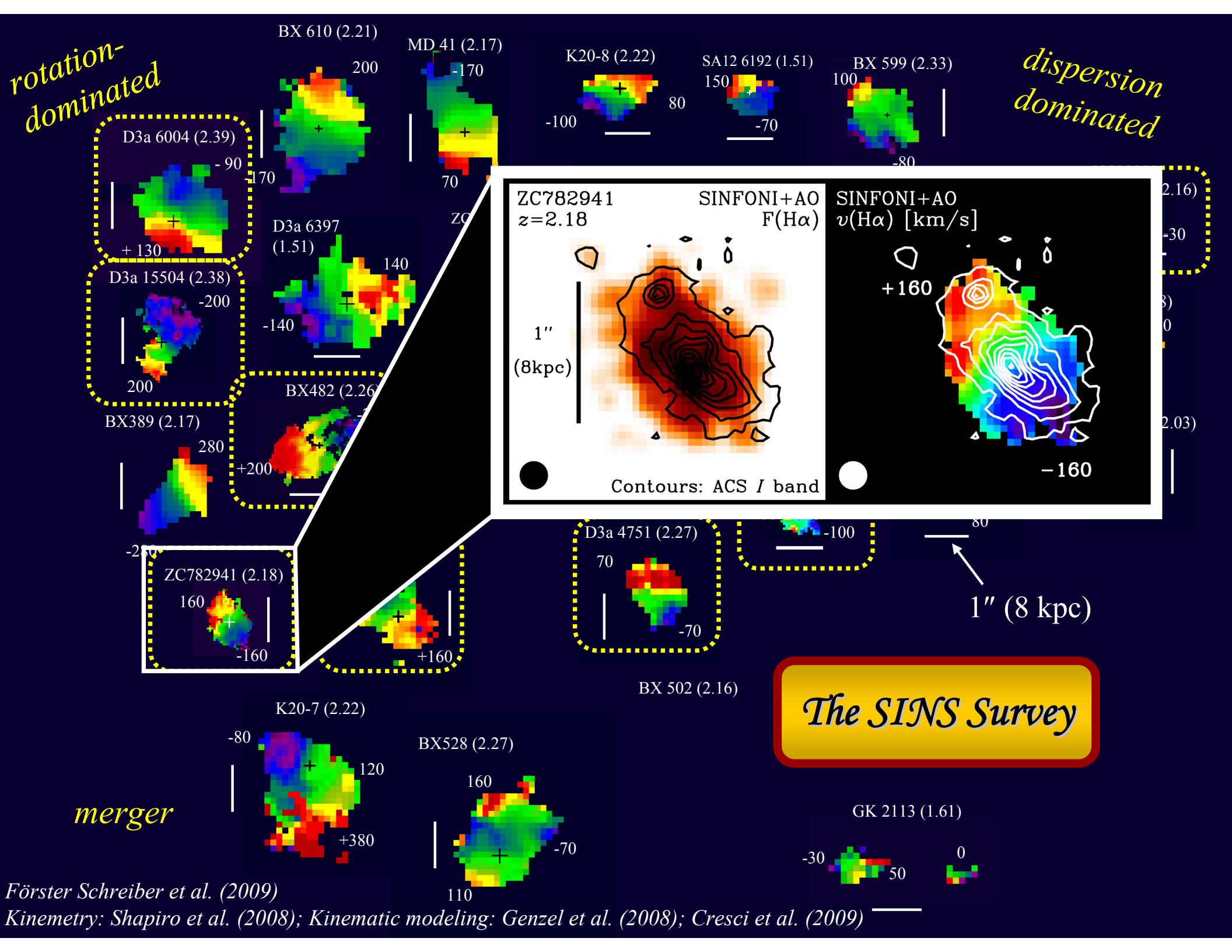


Förster Schreiber et al. (2009)
Kinemetry: Shapiro et al. (2008); Kinematic modeling: Genzel et al. (2008); Cresci et al. (2009)



Förster Schreiber et al. (2009)

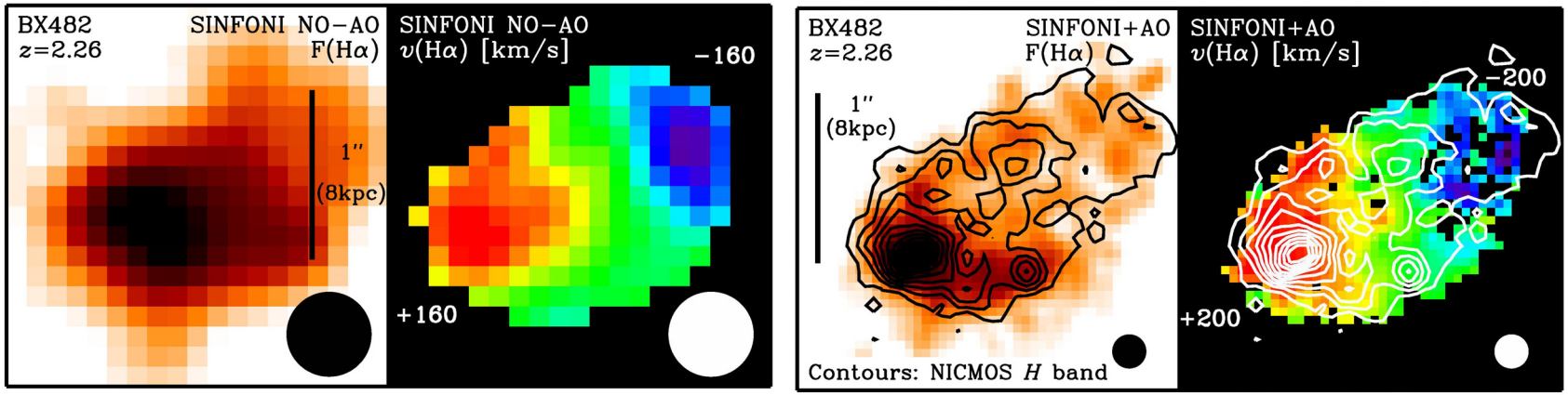
Kinemetry: Shapiro et al. (2008); Kinematic modeling: Genzel et al. (2008); Cresci et al. (2009)

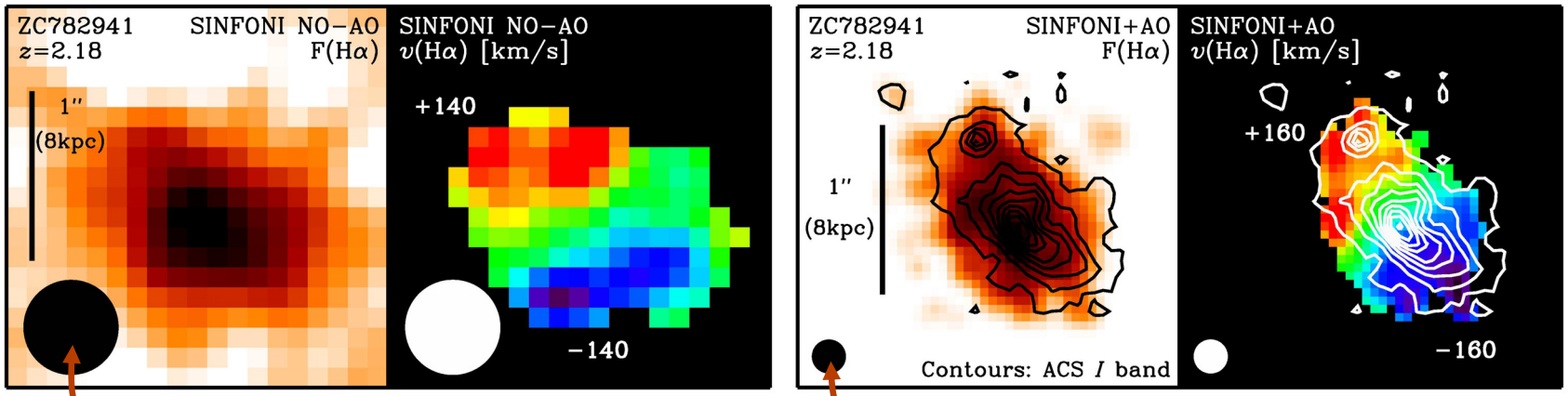


Förster Schreiber et al. (2009)
Kinemetry: Shapiro et al. (2008); Kinematic modeling: Genzel et al. (2008); Cresci et al. (2009)

Spatial Resolution Gain with AO

no AO *with* AO

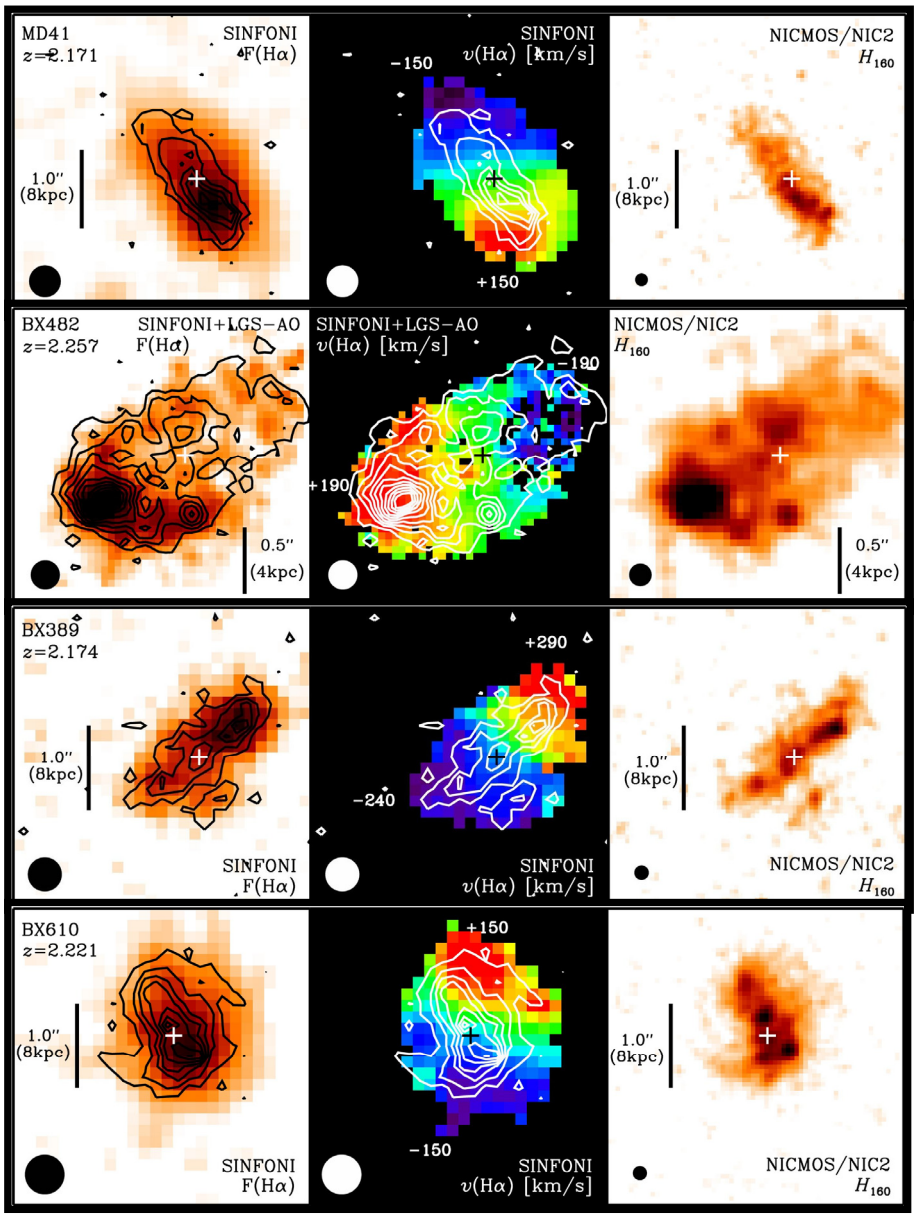




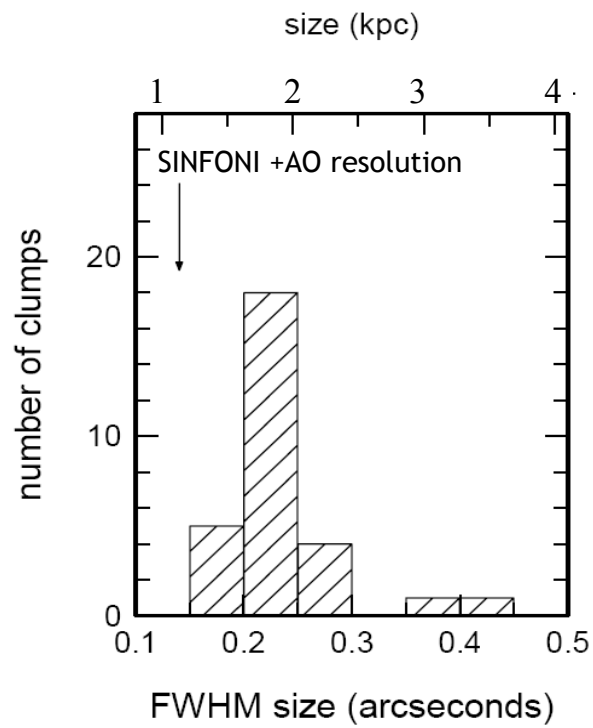
PSF FWHM 0".5

PSF FWHM 0".18

Dynamical Evolution of Gas-rich Disks

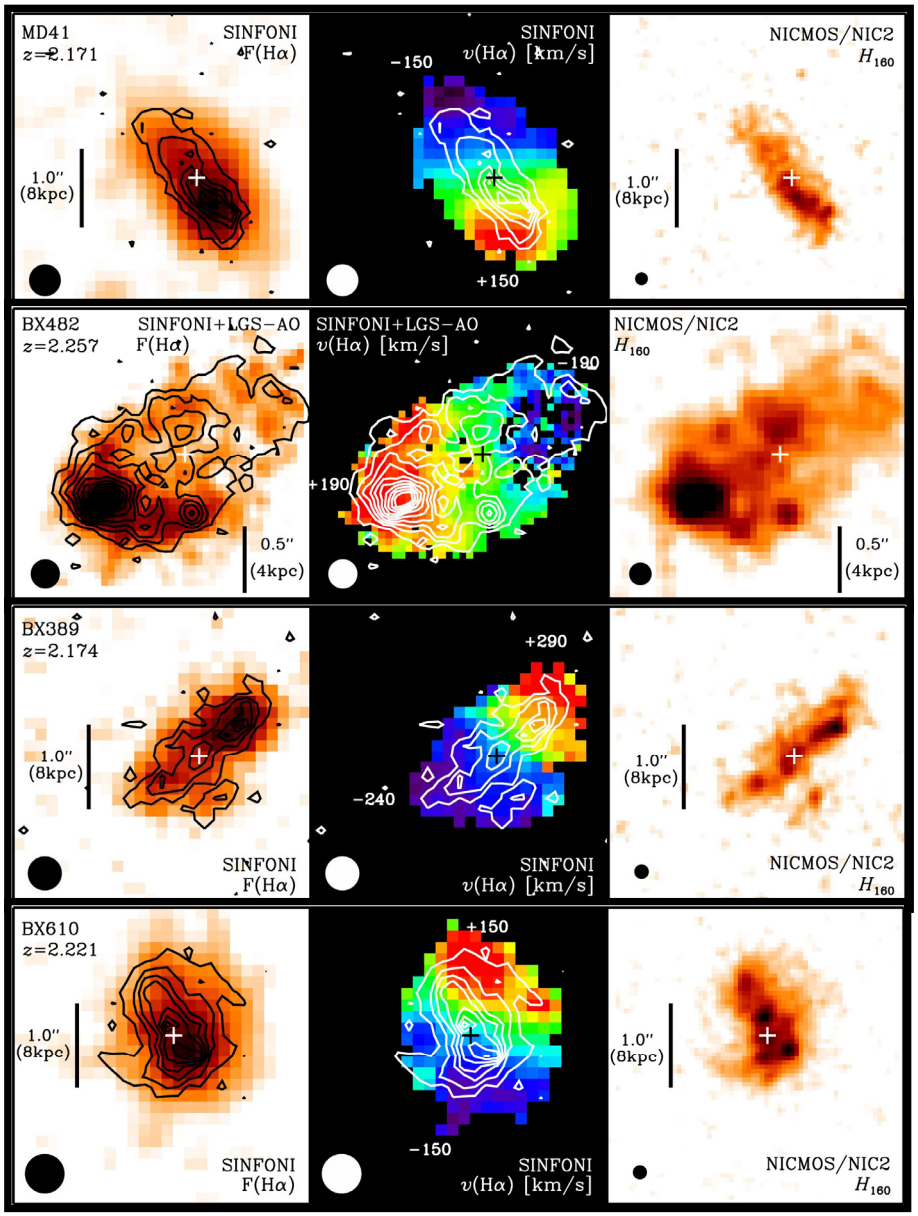


Förster Schreiber, Shapley, et al. (2009); Genzel et al. (2008)

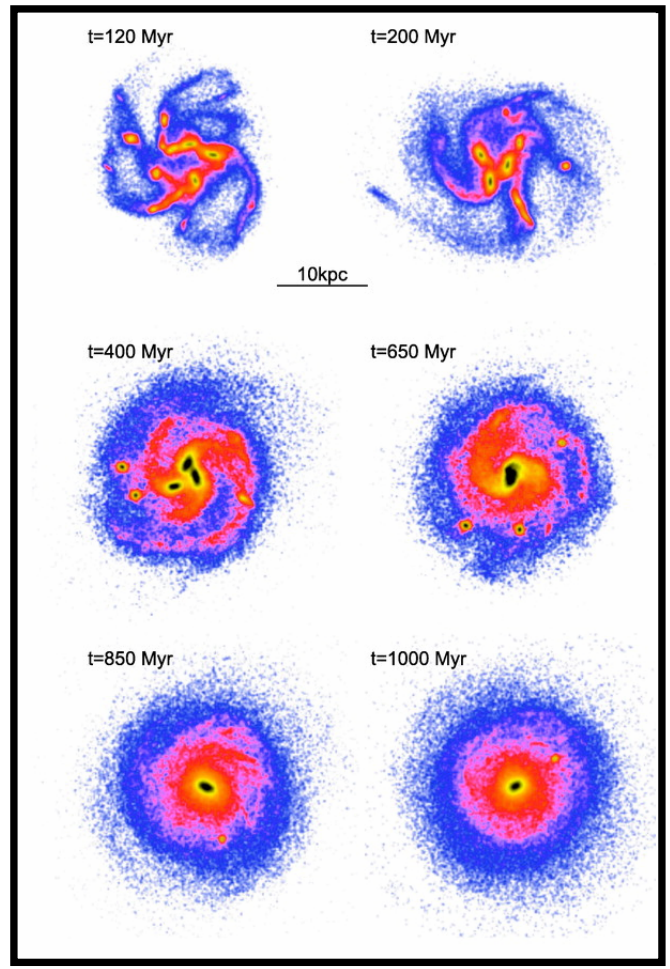


(Also, Cowie et al. 1995; van den Bergh et al. 1996; Giavalisco et al. 1996; Conselice et al. 2004; Lotz et al. 2004; Papovich et al. 2005; Toft et al. 2007; Law et al. 2007; Elmegreen, Elmegreen, et al. 2004-2008; and others)

Dynamical Evolution of Gas-rich Disks

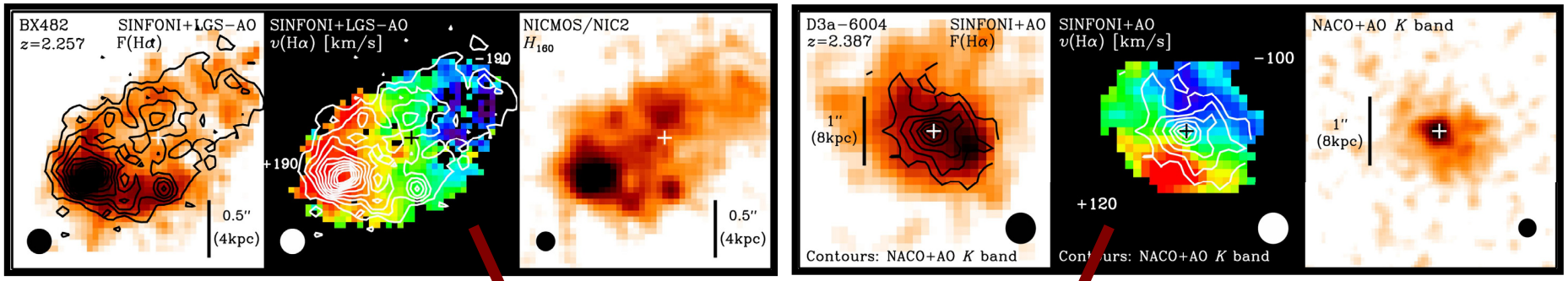


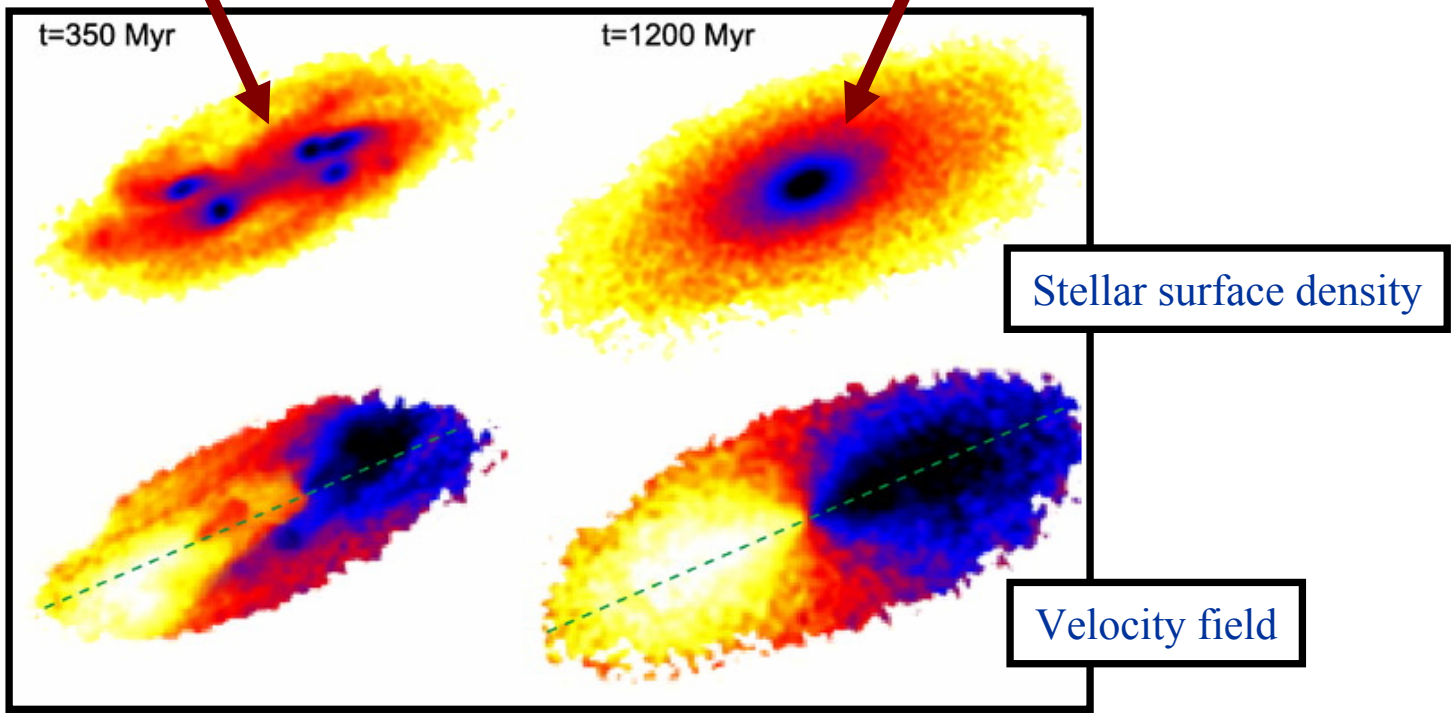
Förster Schreiber, Shapley, et al. (2009); Genzel et al. (2008)



Bournaud et al. (2007; 2008)
Also, e.g., Noguchi (1999); Immeli et al. (2004a, b); Semelin & Combes (2002); Naab et al. (in prep.)

Dynamical Evolution of Gas-rich Disks

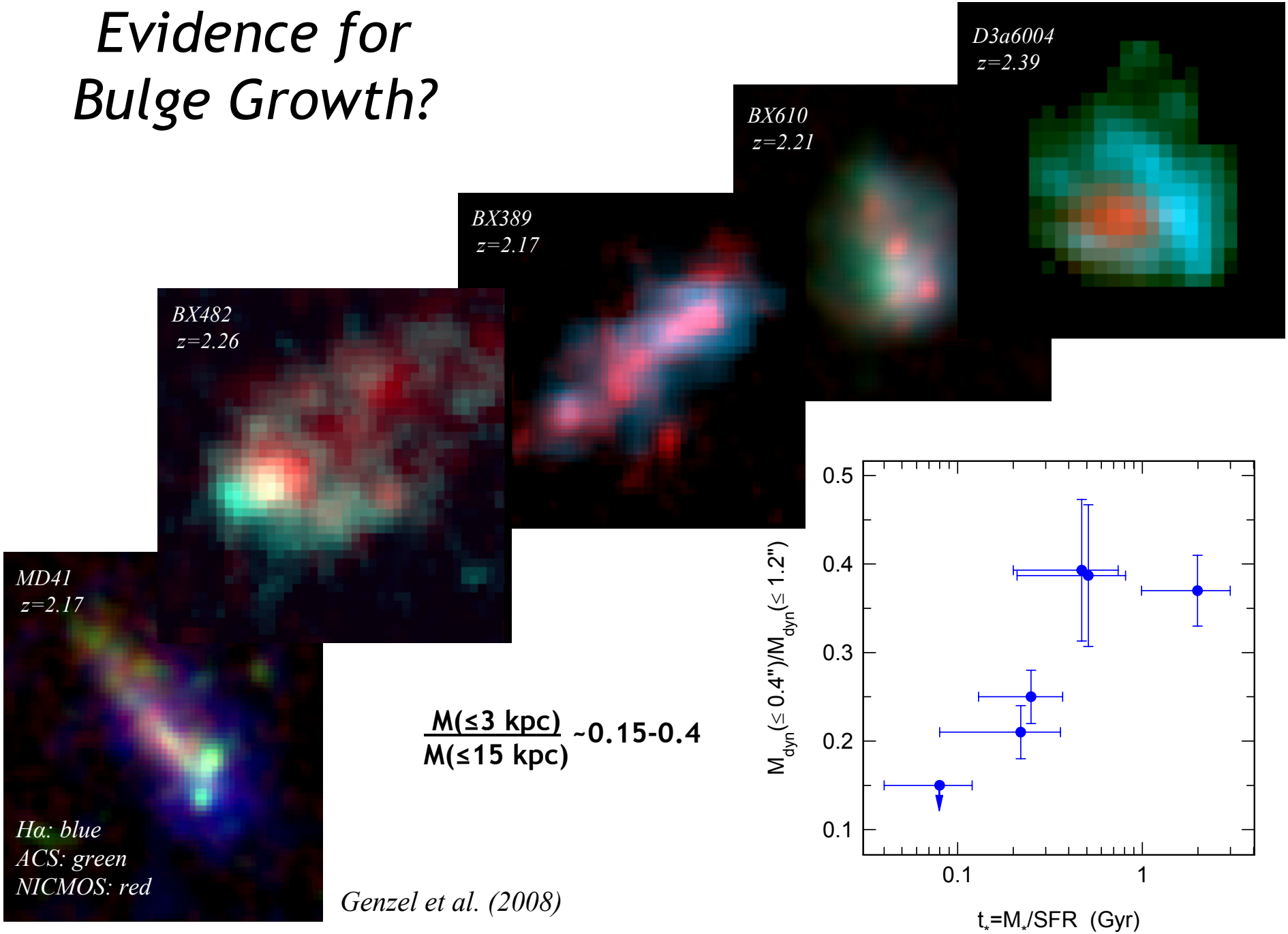




Bournaud et al. (2007; 2008; 2009)
Also: Immeli et al. (2004a,b); Naab et al. (in prep.)

Förster Schreiber, Shapley, et al. (2009); Genzel et al. (2008)

Evidence for Bulge Growth?



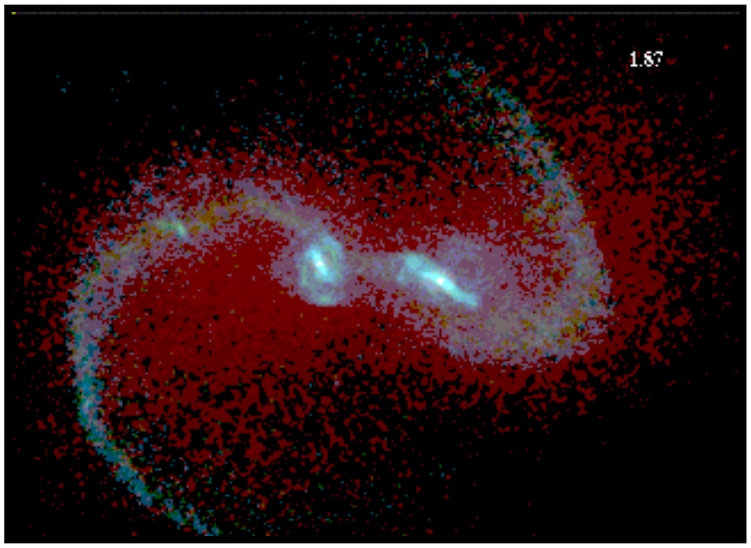
$$\frac{M(\leq 3\ \mathrm{kpc})}{M(\leq 15\ \mathrm{kpc})} \sim 0.15\text{-}0.4$$

Genzel et al. (2008)

Rapid Star Formation/Mass Accretion: Major Mergers or Smoother Infall?

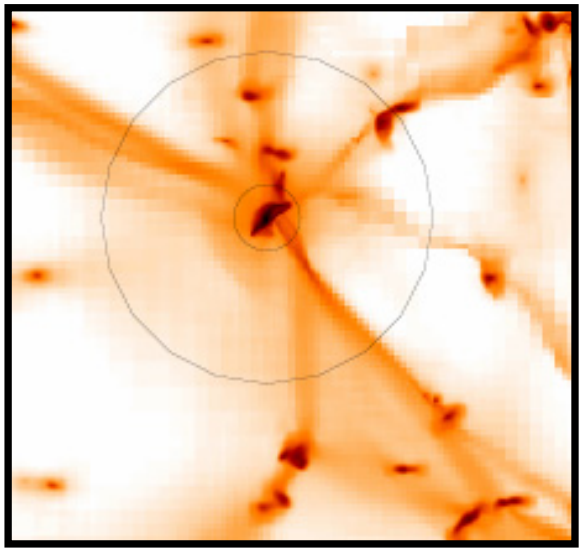
$\tau_\star \sim \tau_{gas} \sim 500\,\mathrm{Myr} \sim \text{several } \tau_{dyn} << t_{Hubble}$

Major mergers



(e.g., Toomre & Toomre 1972; Barnes & Hernquist 1996; Springel & Hernquist 2005; di Matteo et al. 2005; Naab & Burkert 2003,2006; Hopkins et al. 2006; Tacconi et al. 2006,2008; Swinbank et al. 2006 Robertson et al. 2008)

Cold flows/minor mergers

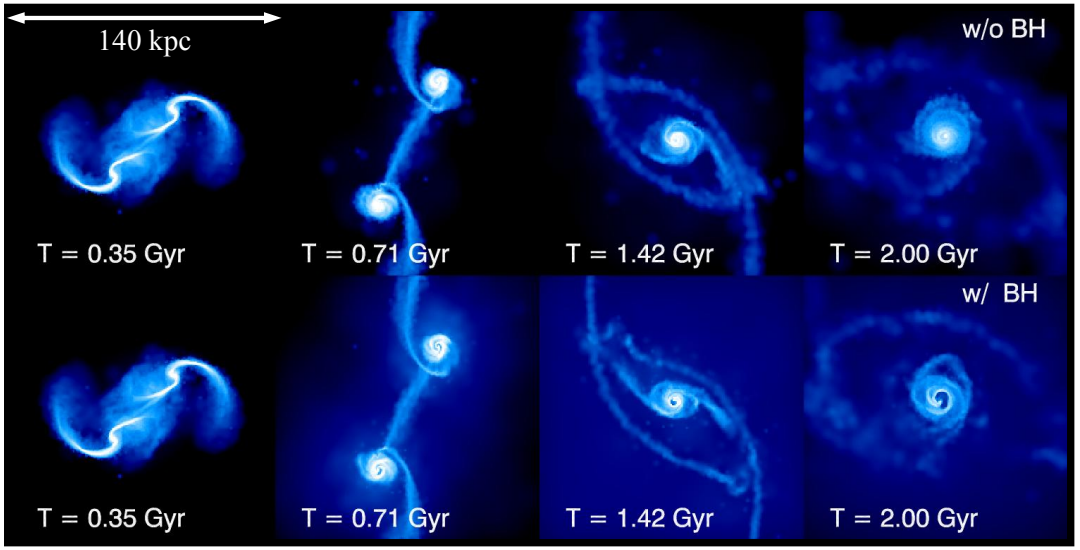


(e.g., Dekel & Birnboim 2003,2006; Kereš et al. 2005; d'Onghia et al. 2006; Kitzbichler & White 2007; Guo & White 2008; Davé 2008; Noeske et al. 2007; Elbaz et al. 2007; Daddi et al. 2007; Dekel et al. 2008, 2009; Genel et al. 2008, 2009)

Subsequent Evolution

Major mergers?
Secular evolution?

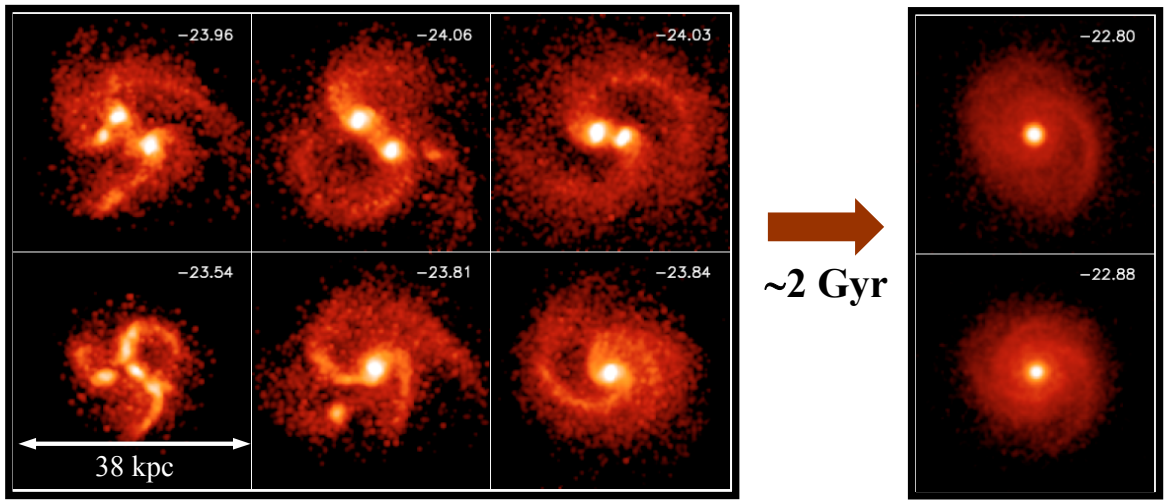
Gas-rich mergers + vigorous feedback



Robertson et al. (2005)

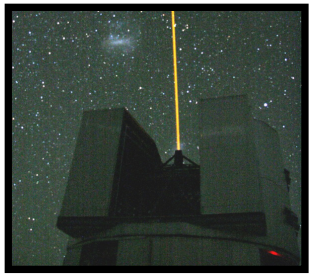
Gas-rich star-forming disk: disk fragmentation + bulge formation

e.g., Noguchi 1999;
van den Bosch 2002;
Croton et al. 2005;
Governato et al. 2006, 2007;
Dekel et al. 2007;
Bournaud et al. 2007; 2008;
Carollo et al. 2007; and others



Immeli, Gerhard, et al. (2004)

SINS Key Results



- *Kinematics of SINS massive star-forming galaxies at z ~ 2*
  - **~1/3 rotation-dominated, ~1/3 compact dispersion-dominated, ~1/3 mergers**
  - **Fraction of rotation-dominated systems increase at higher masses**
- *Properties of massive z ~ 2 star-forming disks*
  - **Significantly more turbulent and gas-rich than local disks**
  - **Higher SFRs, large luminous/massive clumps**
- *Mass assembly, early evolution, and star formation activity*
  - **Evidence for smooth+rapid mass accretion via cold flows/minor mergers**
  - **Evidence for internal/secular processes in gas-rich disks & rapid bulge formation**