Alison Crocker, Reed College (Lowell Observatory)

Secular Evolution

Roles in galaxy transformation

Define

‘Secular’

Slow and steady processes internal to a galaxy.

Define

‘Secular’

Slow and steady processes internal to a galaxy.

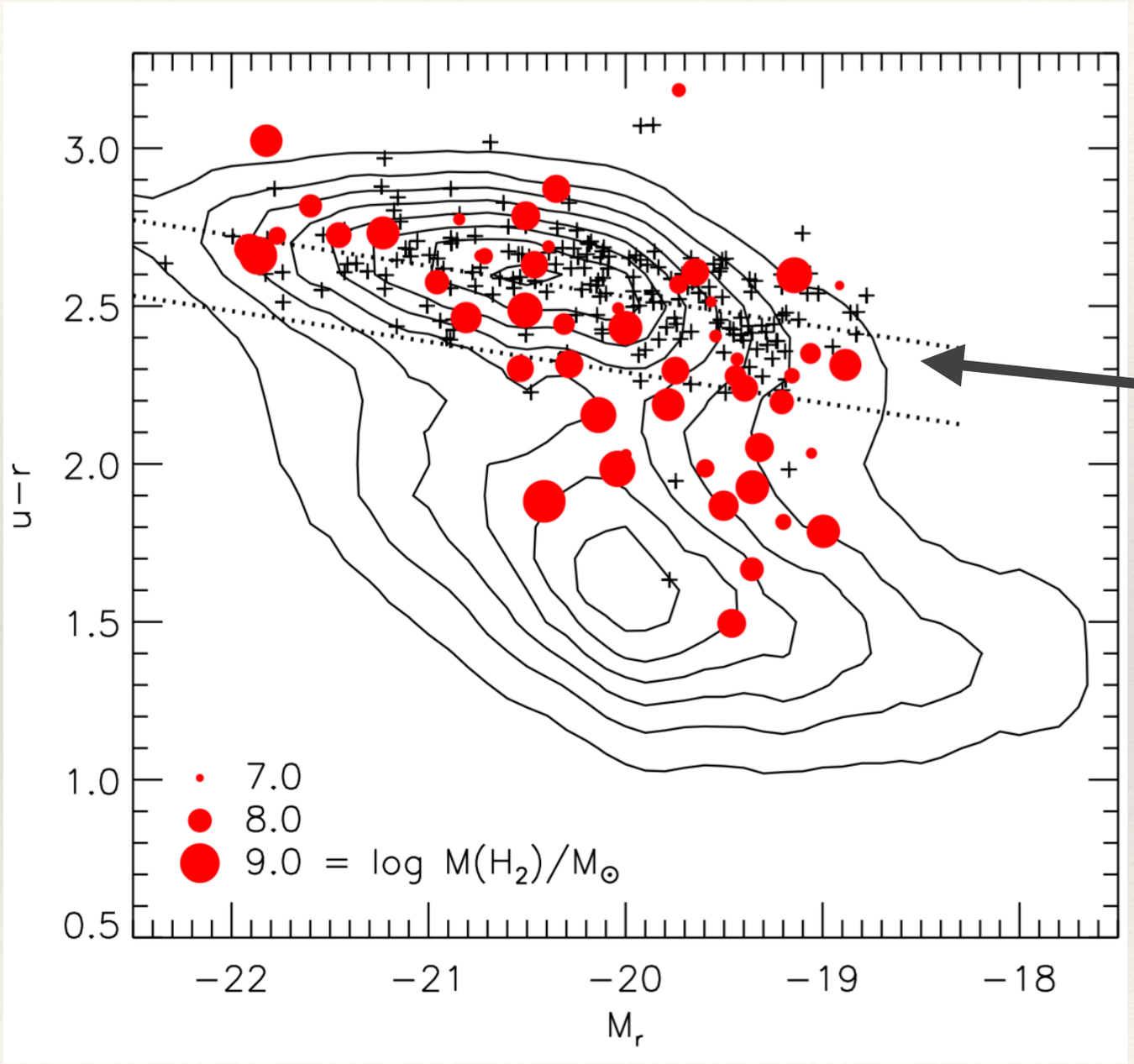
<u>Not</u> caused by:

- mergers
- AGN feedback
- violent disk instabilities
- environment

Secular processes

- 1) Morphological quenching
- 2) Bars
- 3) Hot halo quenching

Morphological quenching



Galaxies on red sequence with significant molecular gas.

Young et al. 2011

Look at gas disk stability:

$$Q = \frac{\kappa\sigma}{\pi G\Sigma}$$

Toomre's instability parameter

- valid for differentially rotating, self-gravitating disks

- Q < 1 is unstable

[Thus, also called "Q-quenching". (Dekel & Burkert 2014)]

epicyclic frequency

gas velocity dispersion

$$Q = \frac{\kappa\sigma}{\pi G\Sigma}$$

gas surface density

Toomre's instability parameter

- valid for differentially rotating, self-gravitating disks

- Q < 1 is unstable

epicyclic frequency

gas velocity dispersion

$$Q = \frac{\kappa\sigma}{\pi G\Sigma}$$

gas surface density

Toomre's instability parameter

- valid for differentially rotating, self-gravitating disks

- Q < 1 is unstable

But! A stellar disk can also aid instability:

$$\frac{1}{Q_{\rm tot}} = \frac{1}{Q_{\rm gas}} + \frac{1}{Q_{\rm stars}}$$

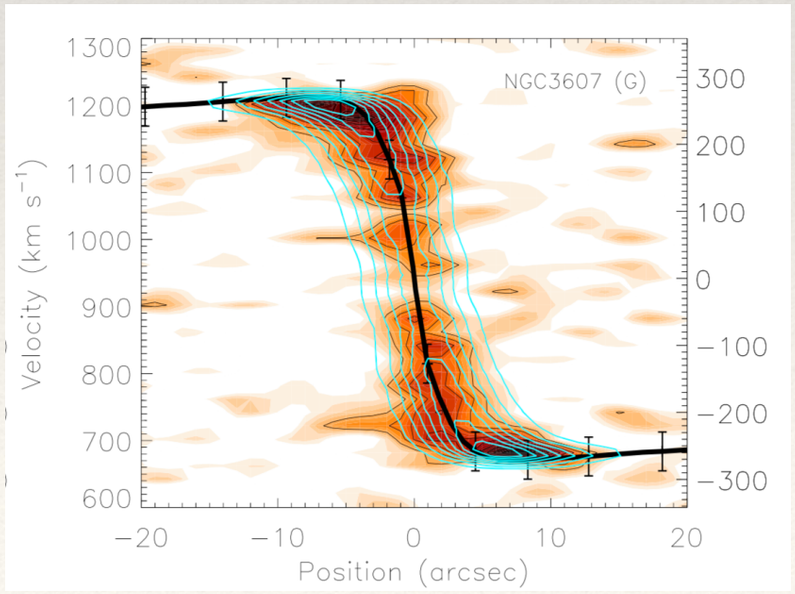
Relevant early-type galaxies features:

1) Insignificant stellar disks -> more stable gas -> lower SF efficiency (Martig et al. 2009, 2013)

Relevant early-type galaxies features:

1) Insignificant stellar disks -> more stable gas -> lower SF efficiency
(Martig et al. 2009, 2013)

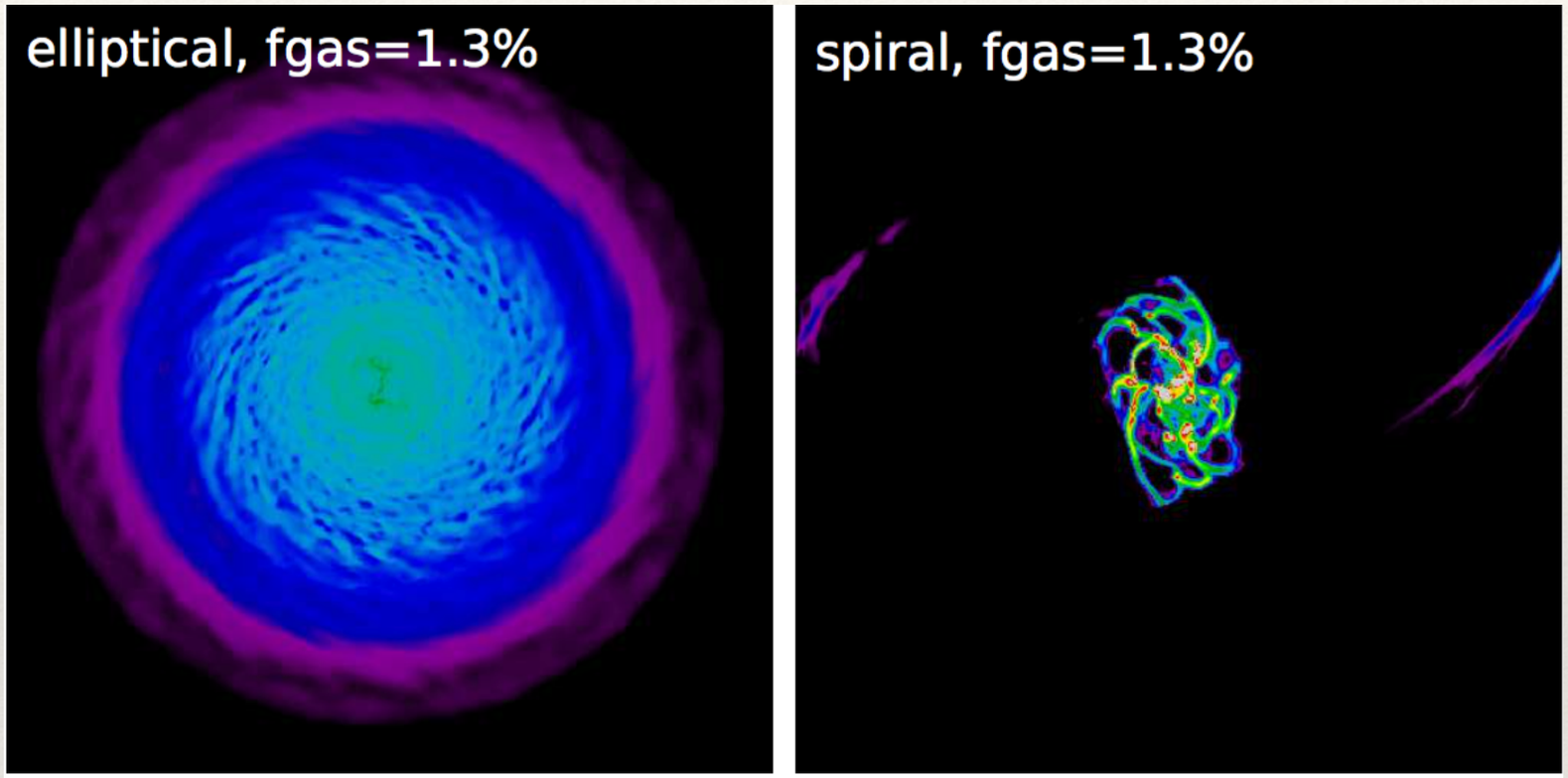
2) High concentration -> more shear -> more stable gas -> lower SF efficiency
(Davis et al. 2014)



[Also called "dynamical quenching".]

Martig, Crocker et al. 2013

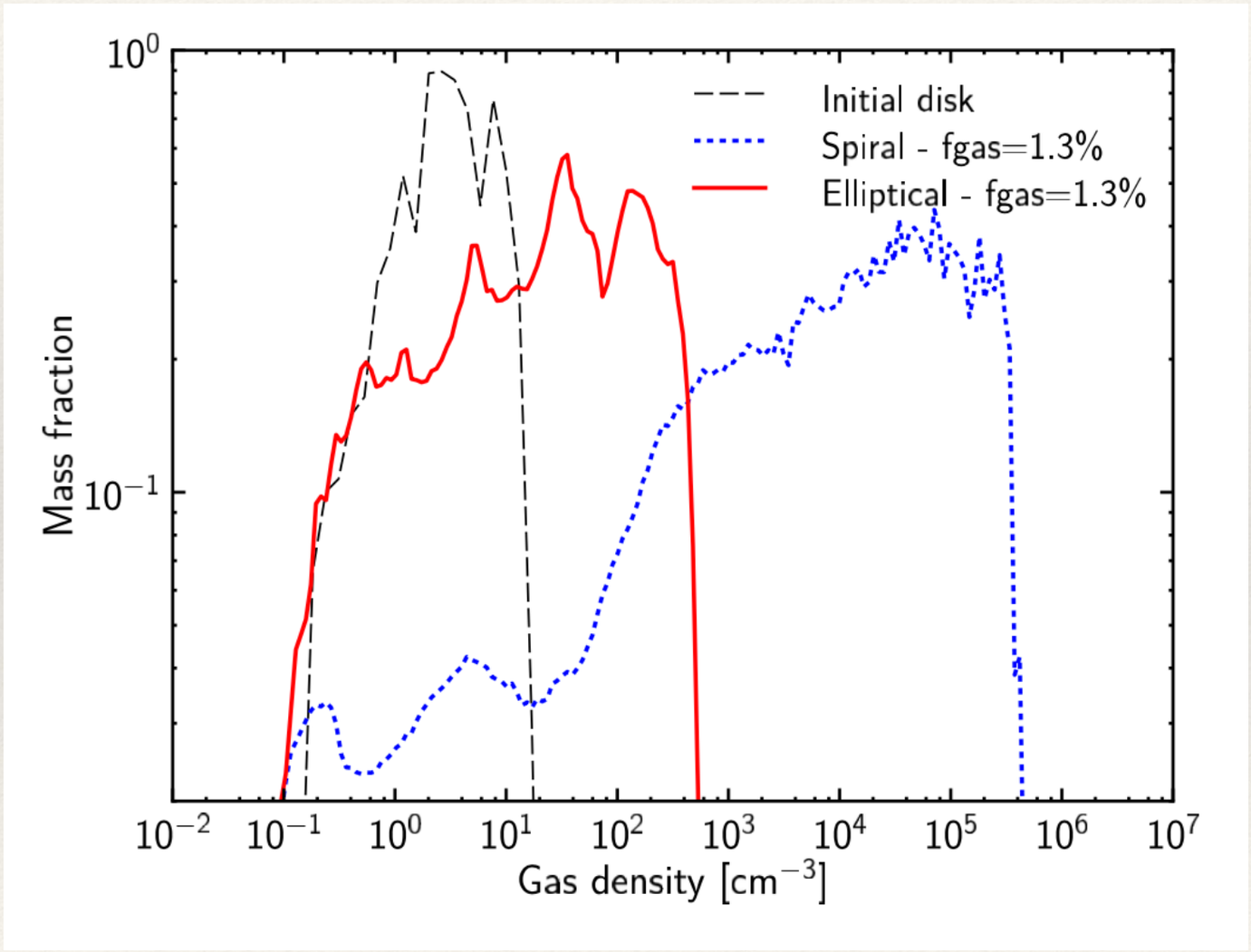
- AMR simulation, 5 pc resolution
- Same initial gas disk in an elliptical and a spiral



SFR = 0.1 Msun/yr SFR = 2.5 Msun/yr

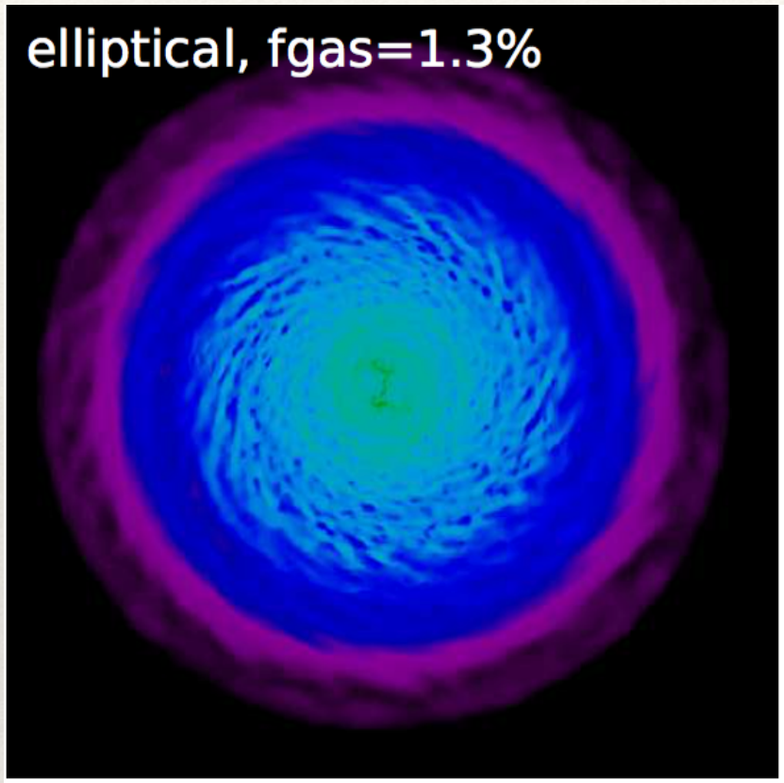
Martig, Crocker et al. 2013

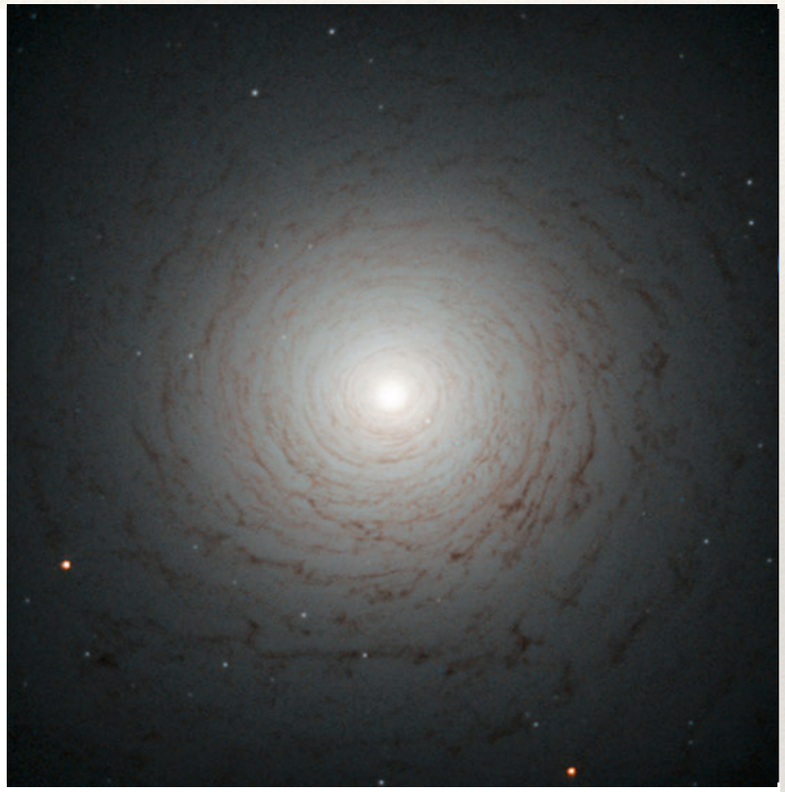
- AMR simulation, 5 pc resolution
- Same initial gas disk in an elliptical and a spiral



Martig, Crocker et al. 2013

- AMR simulation, 5 pc resolution
- Same initial gas disk in an elliptical and a spiral



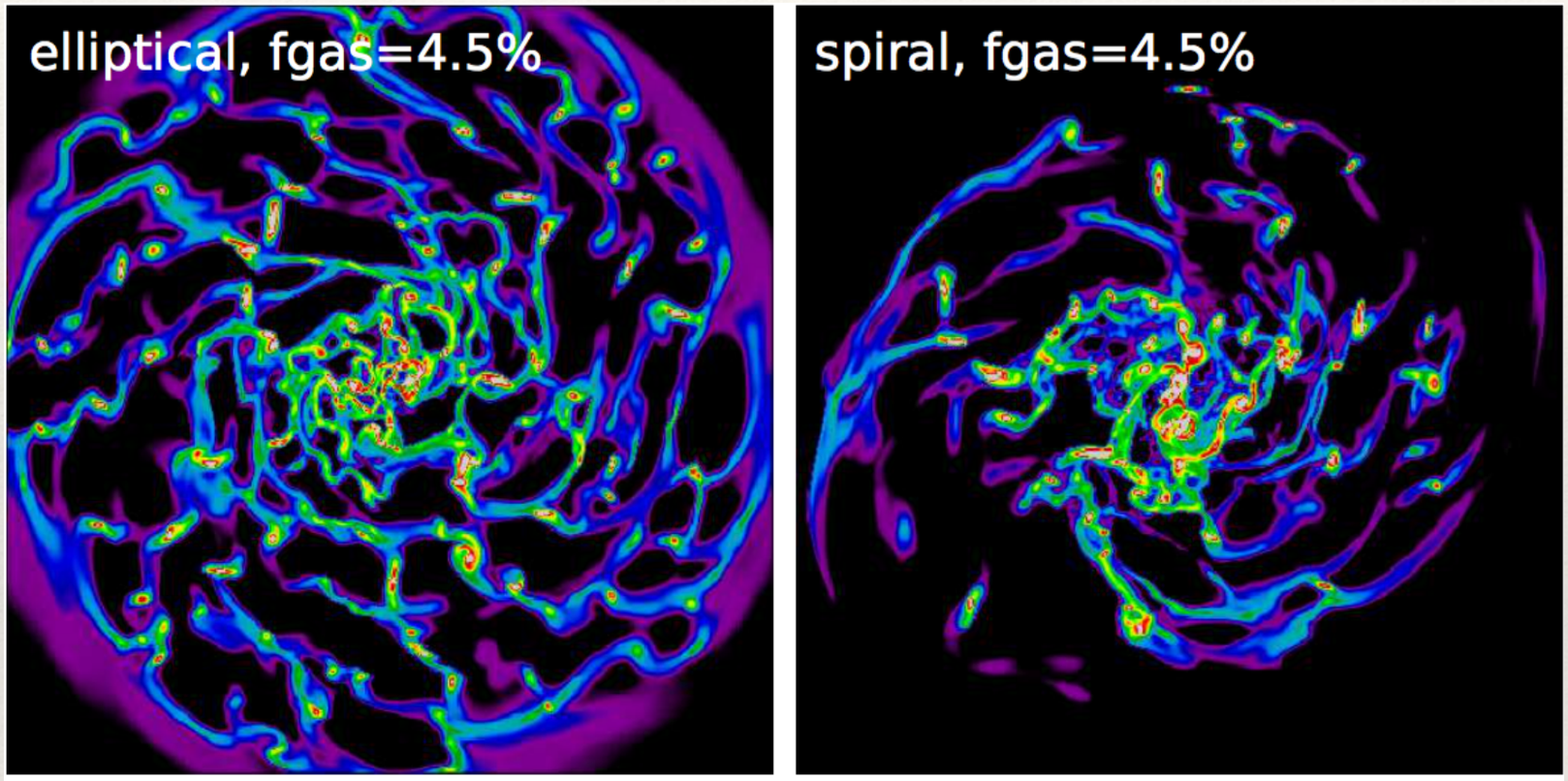


SFR = 0.1 Msun/yr

NGC 524

Martig, Crocker et al. 2013

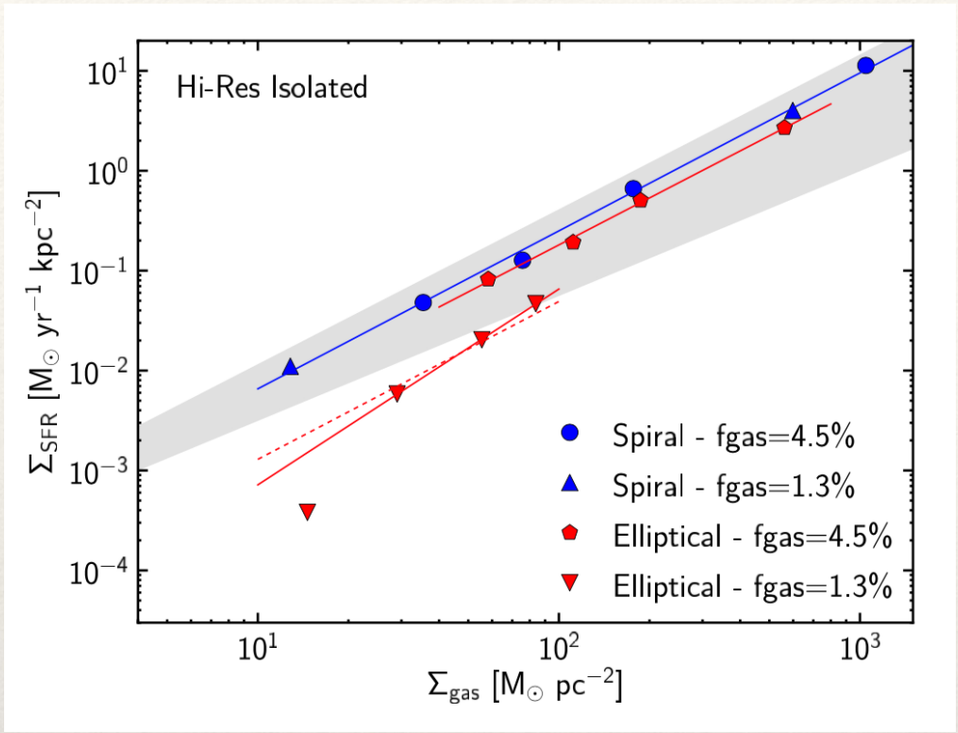
- Effect limited for higher-mass gas disks:



SFR = 4.8 Msun/yr SFR = 11.3 Msun/yr

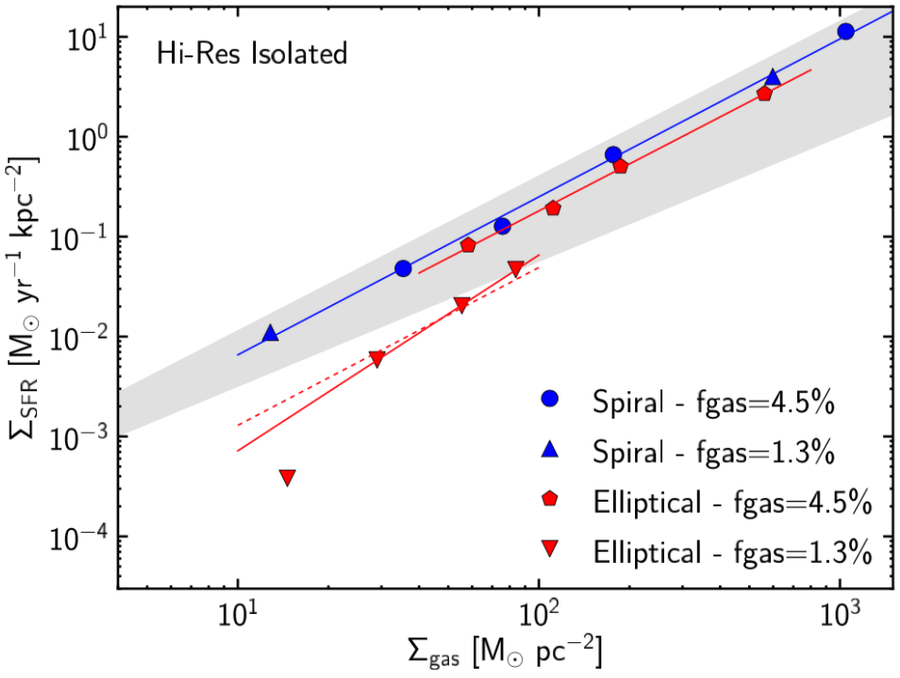
Kennicutt-Schmidt plots

Martig+13 simulation:

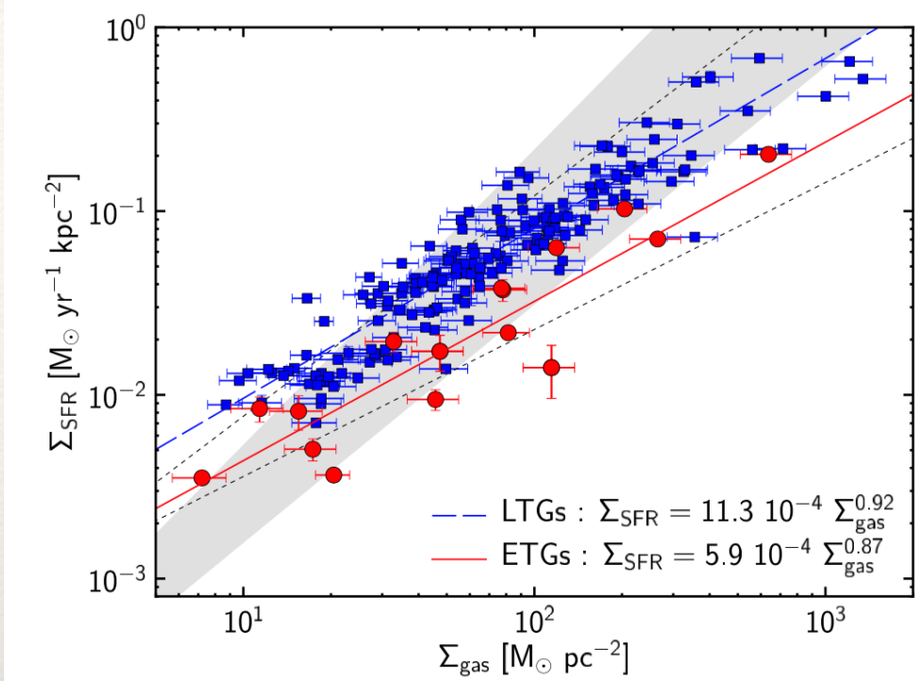


Kennicutt-Schmidt plots

Martig+13 simulation:

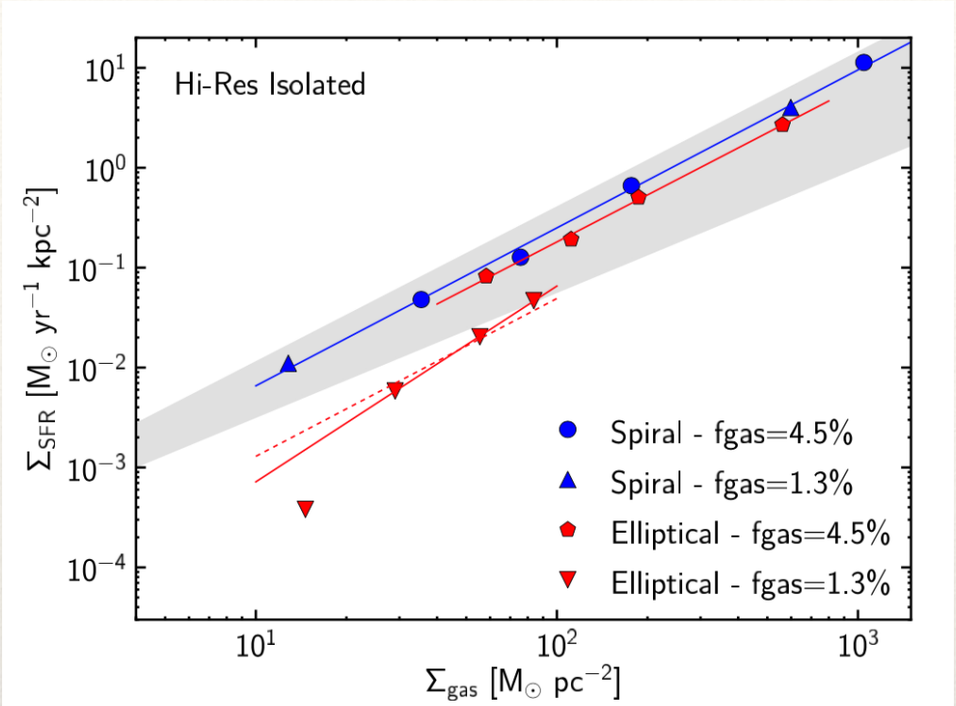


Martig+13 observations:

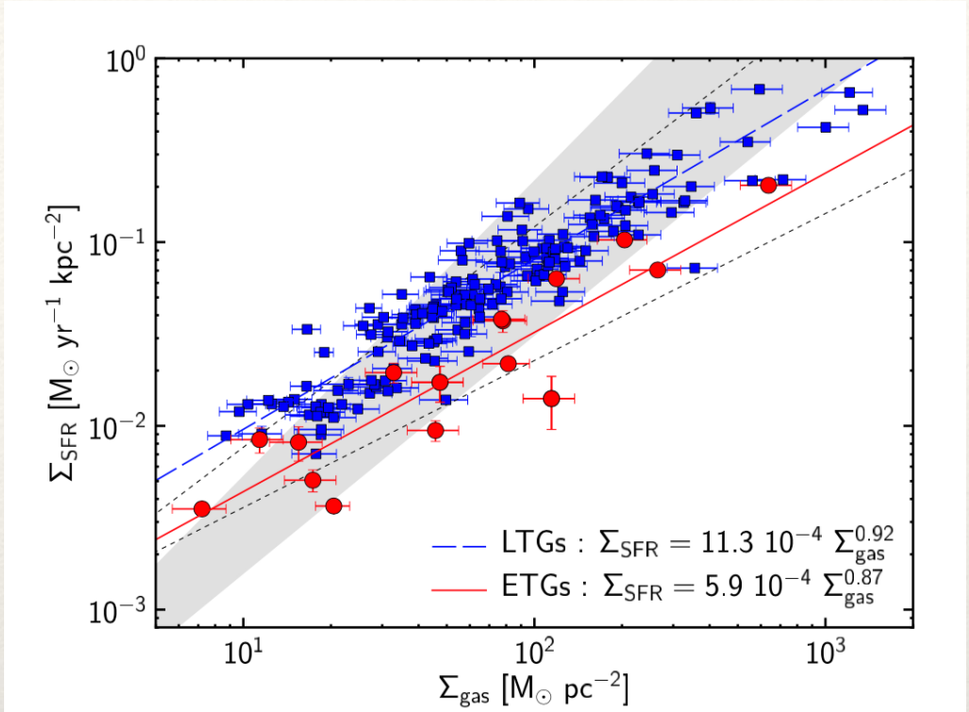


Kennicutt-Schmidt plots

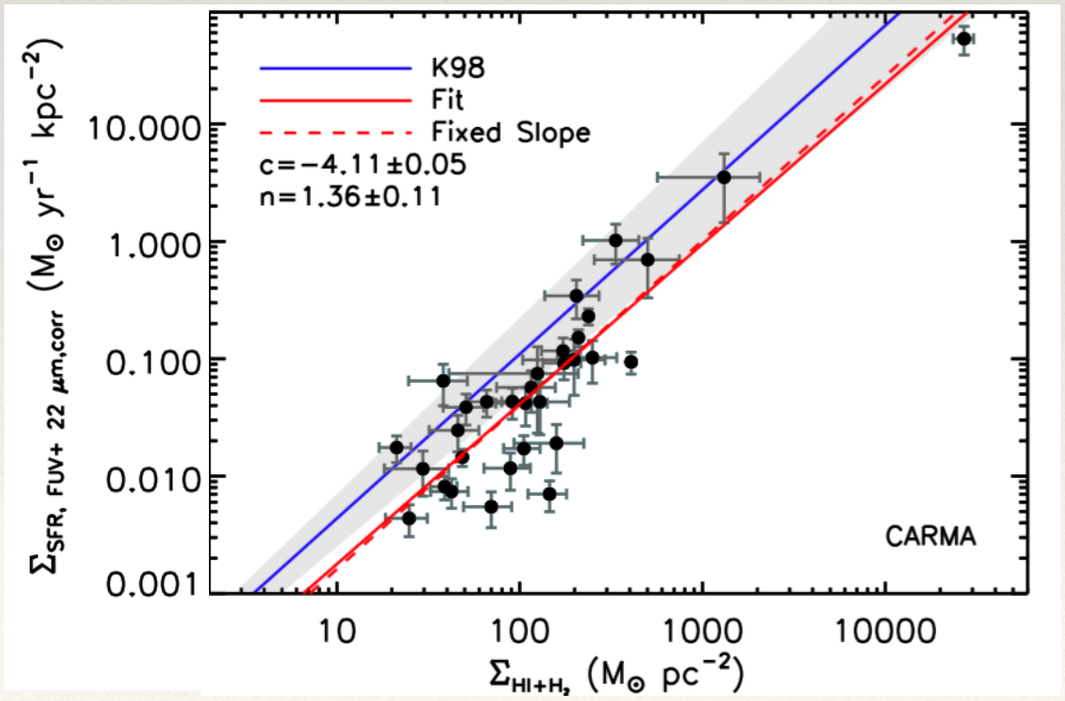
Martig+13 simulation:



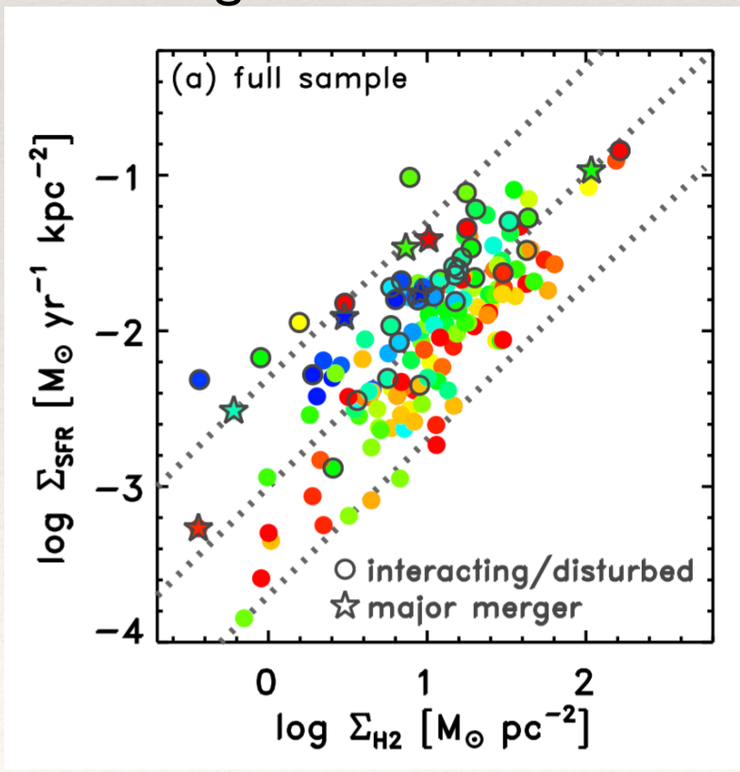
Martig+13 observations:



Davis+14 observations:

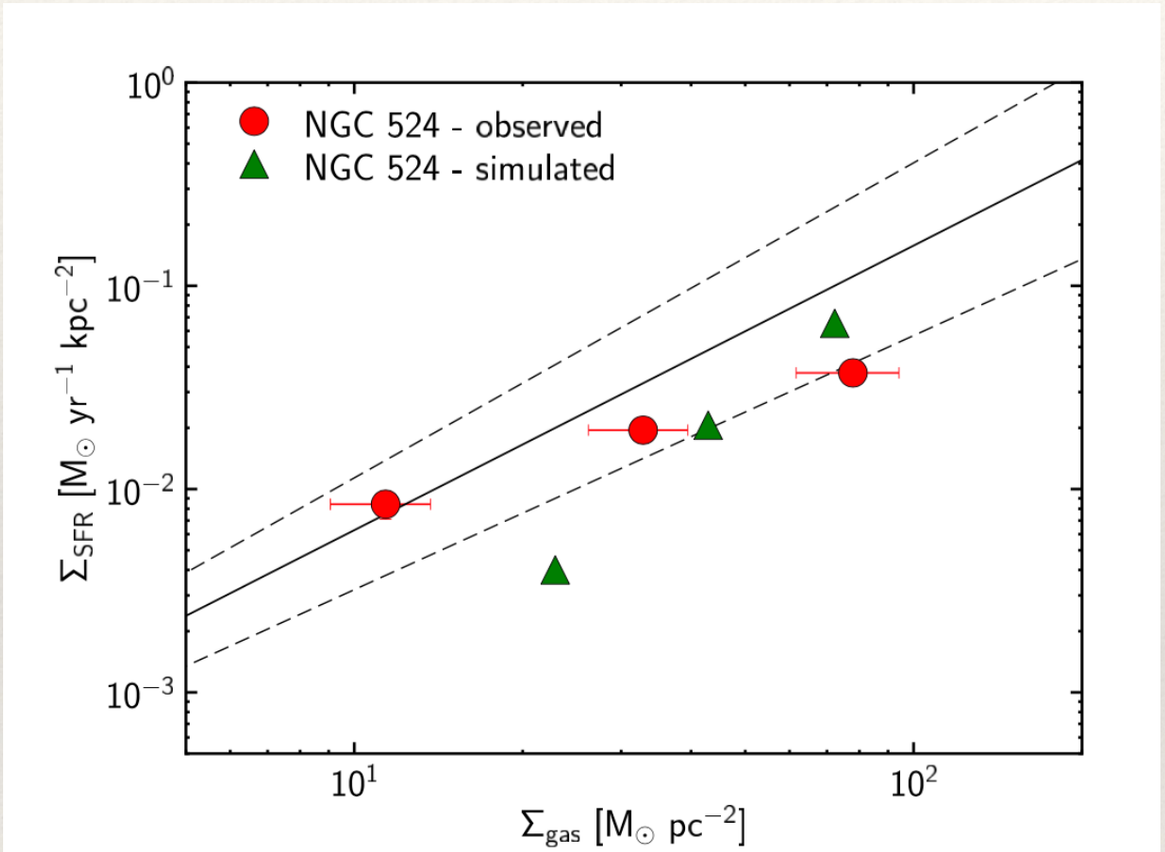


Saintonge+12 observations:



Some tension to this picture…

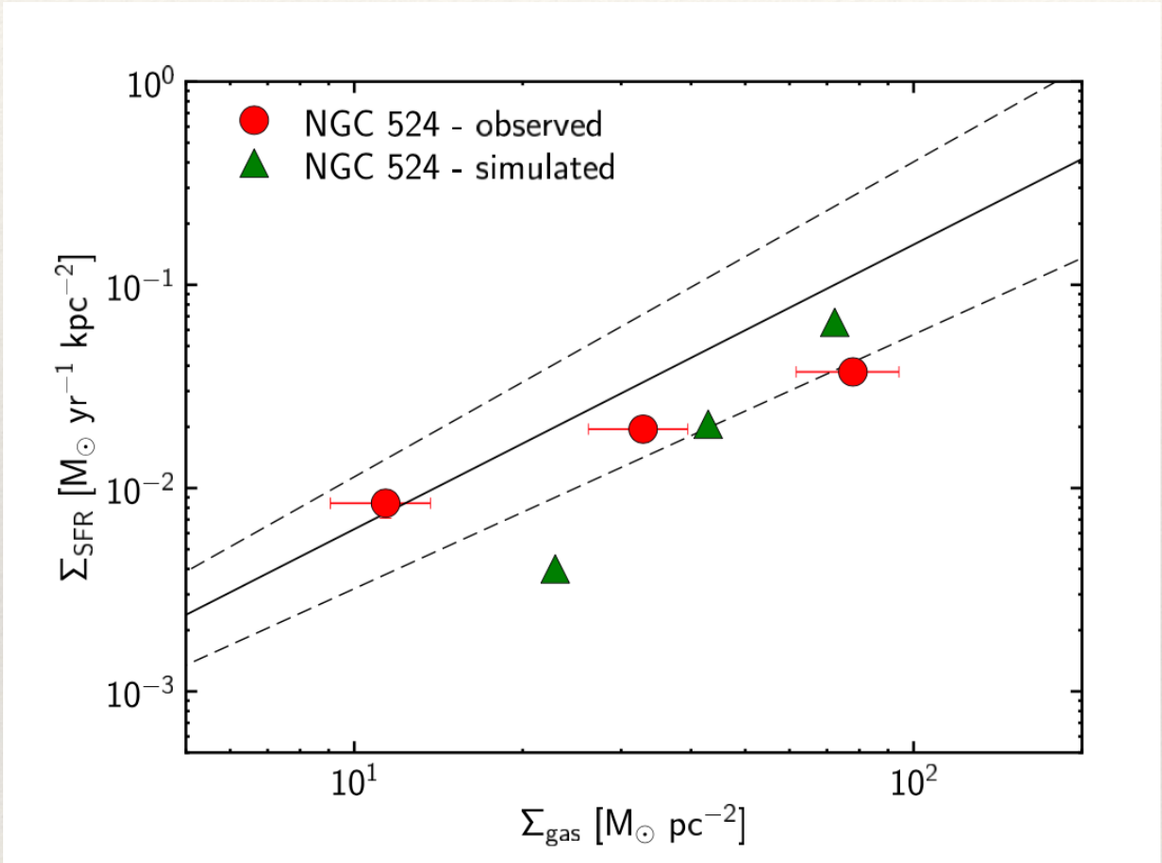
Martig+13:



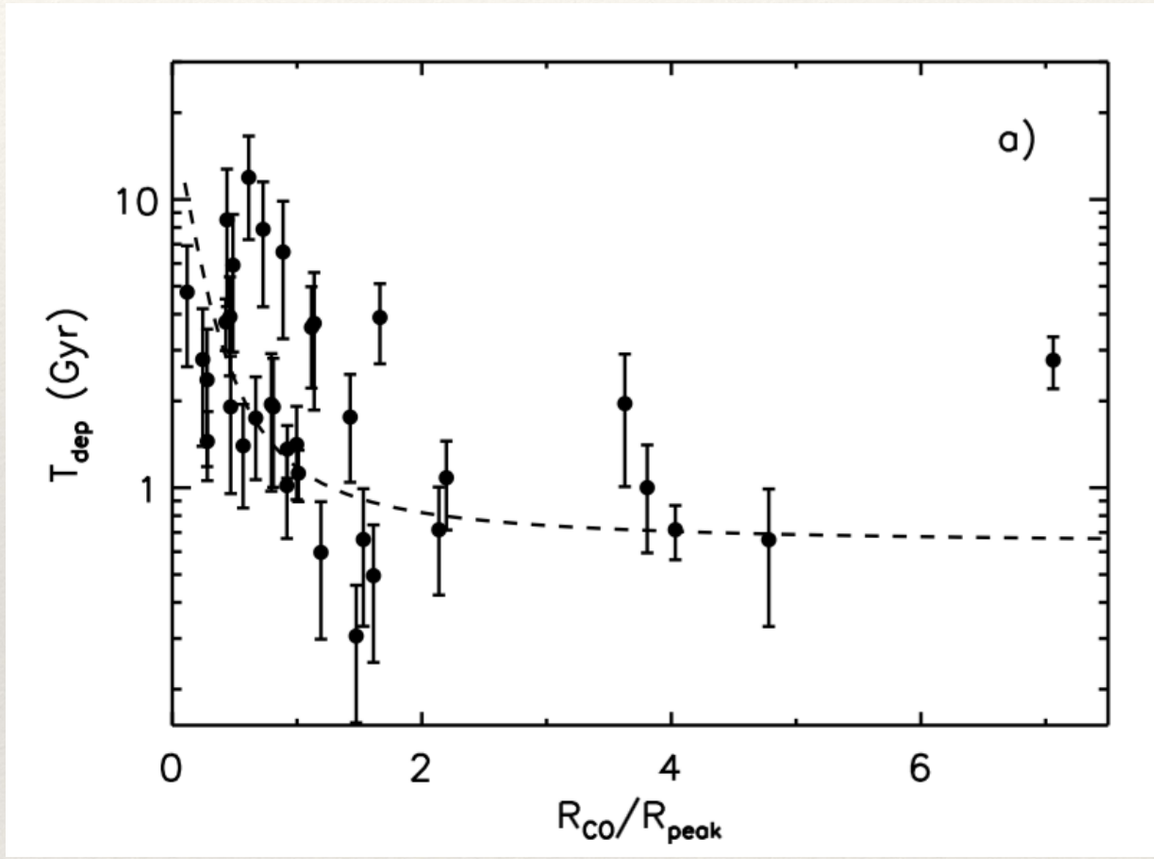
Observed lower efficiency at <u>high</u> gas densities…

Some tension to this picture…

Martig+13:



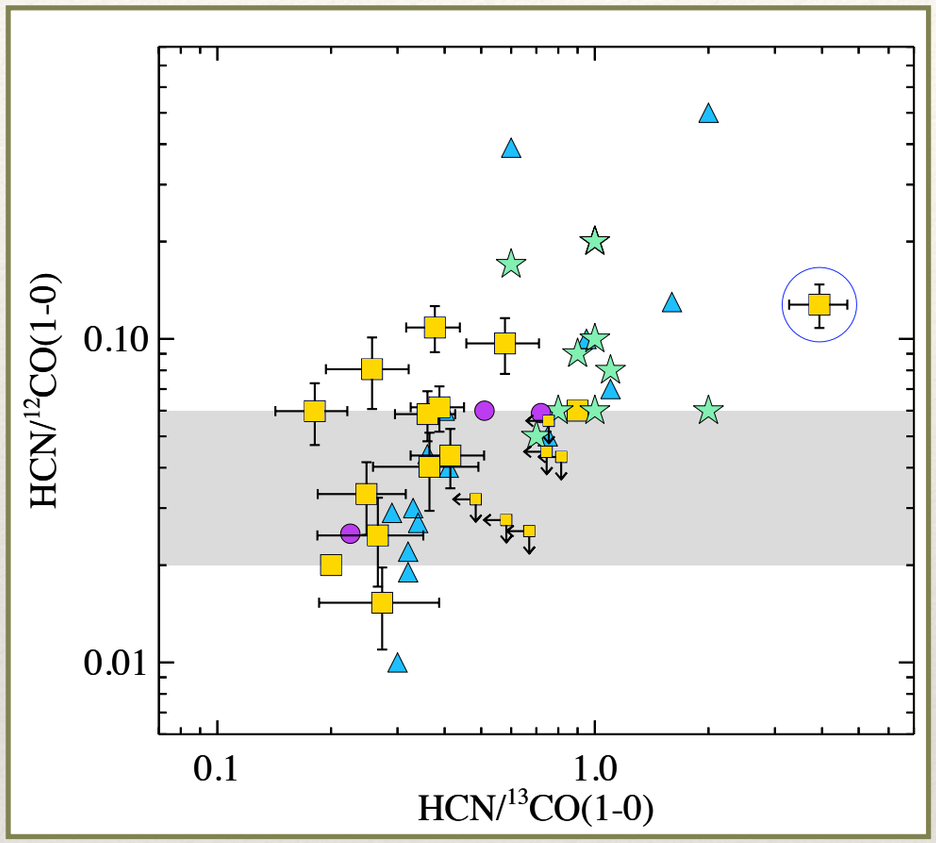
Davis+14:

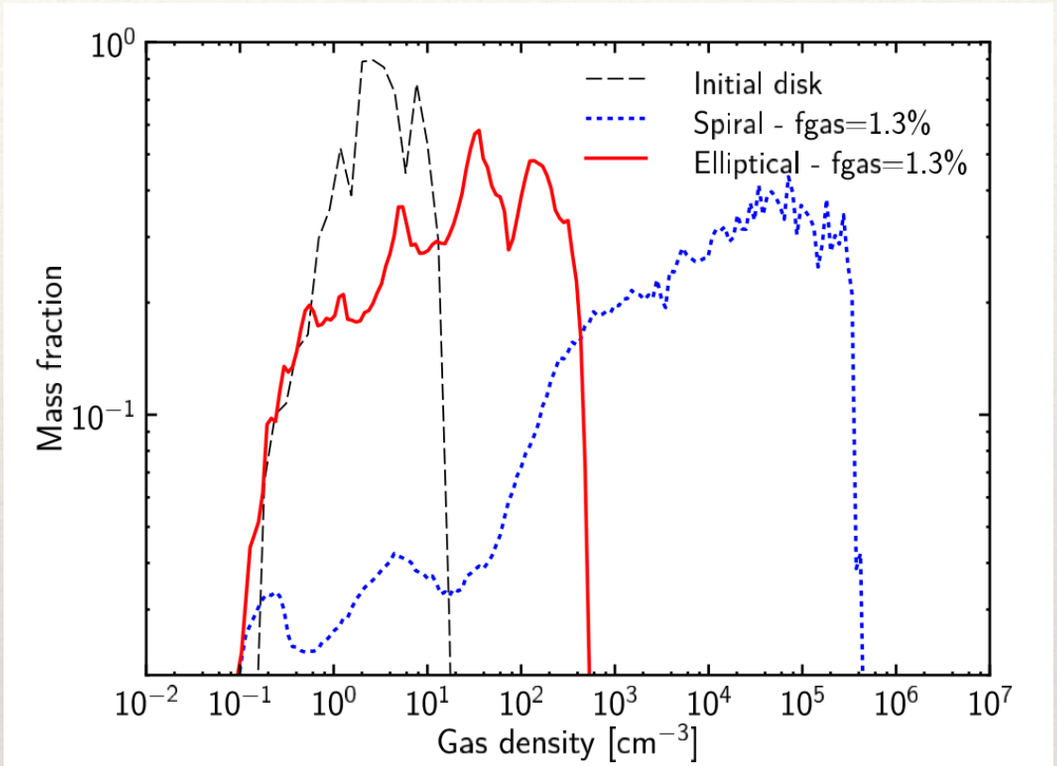


Lower efficiency at <u>high</u> gas densities, in the <u>centers</u> of bulges…

Some tension to this picture…

Crocker+12:

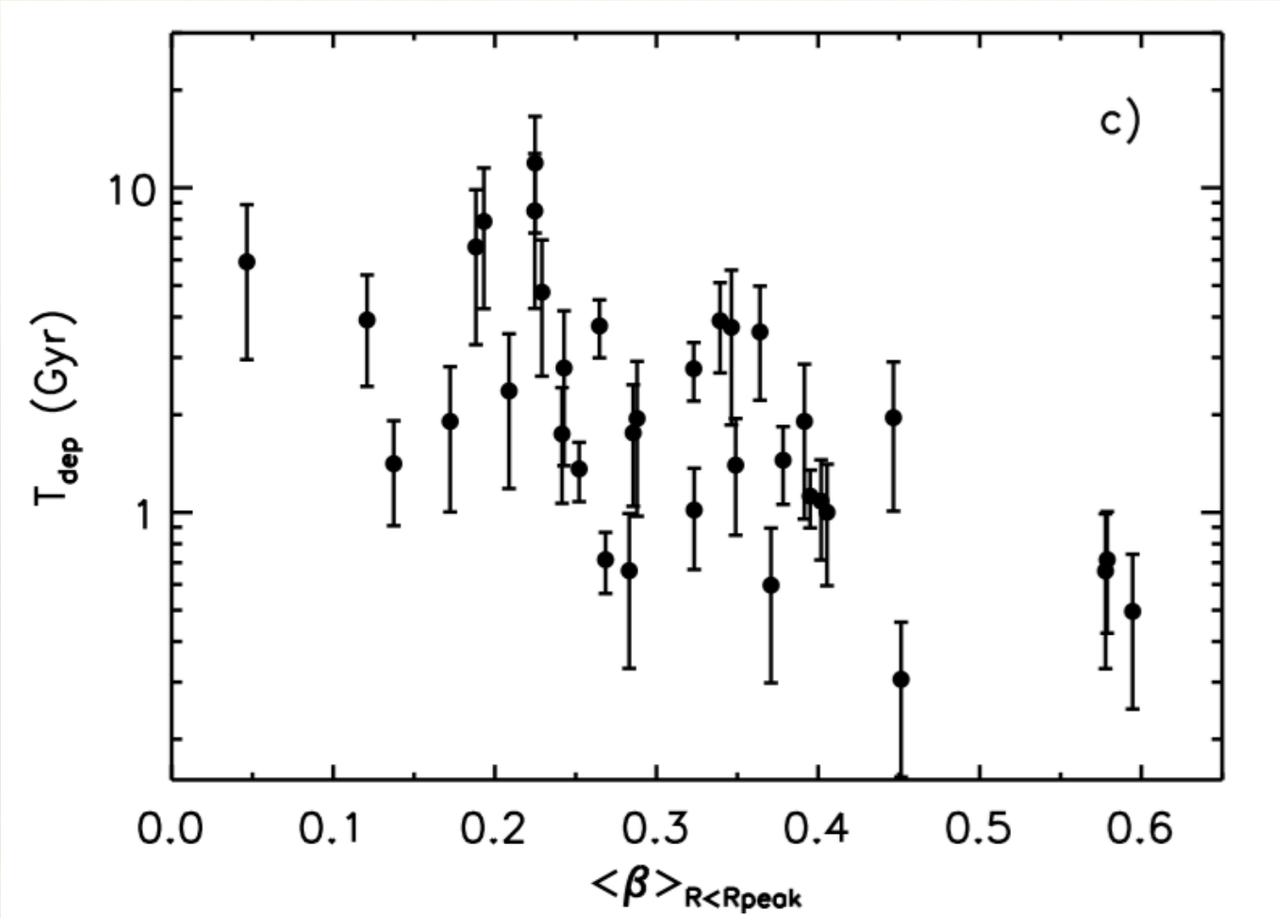




Furthermore, dense gas fractions aren't low in early-type galaxies…

Davis et al. 2014

'Dynamical' quenching hypothesis:
High shear of inner rotation curve is more important.



(See similar argument for stability of central high molecular densities in barred galaxies in Jogee, Scoville & Kenney 2005)

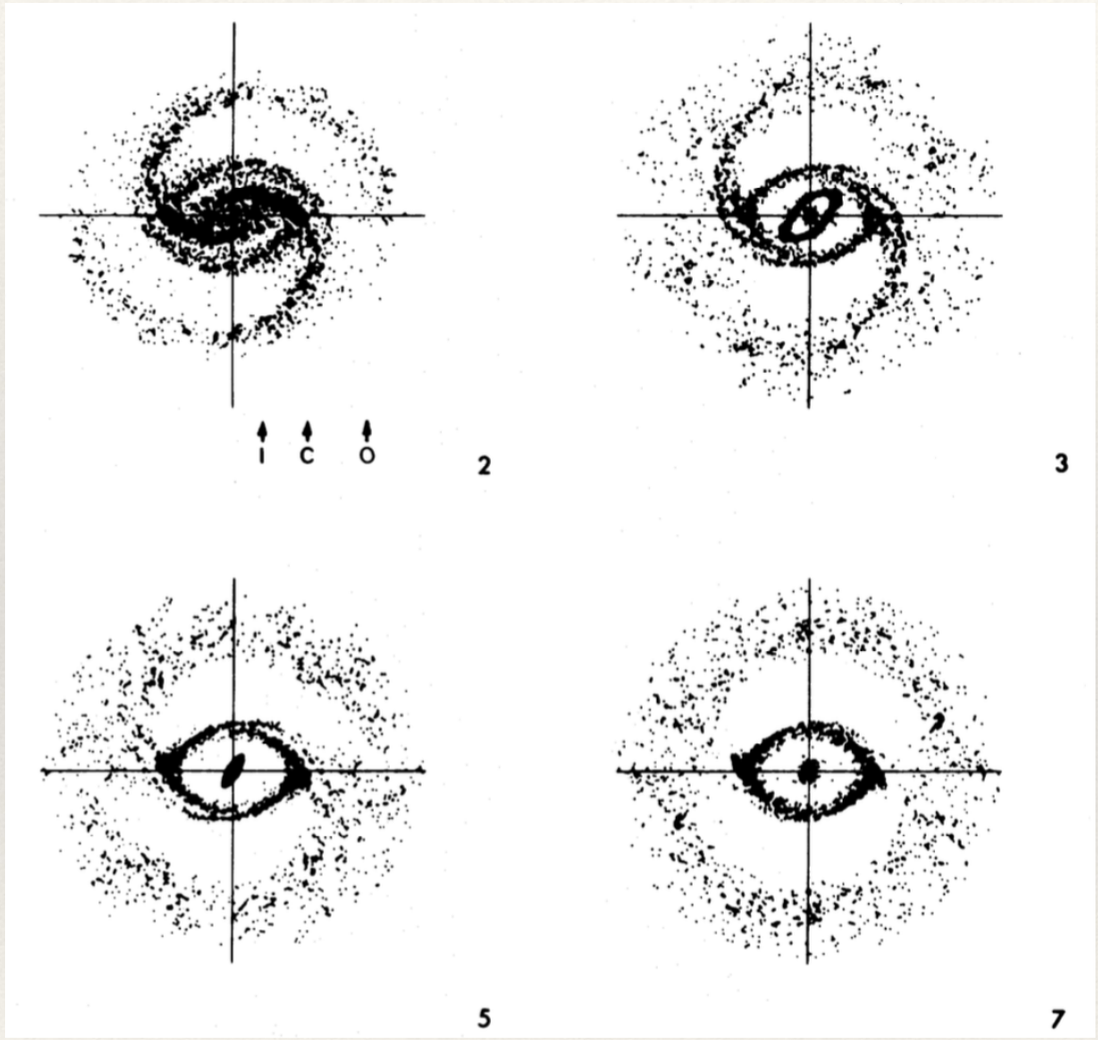
Morphological quenching summary

True, observed effect: lower SFE in early-types.

Both lack of a stellar disk and increased shear should contribute.

Observational signs of high differential rotation being more important.

Bars



Simkin, Shu, & Schwarz 1980

Transport gas inward (and outward).

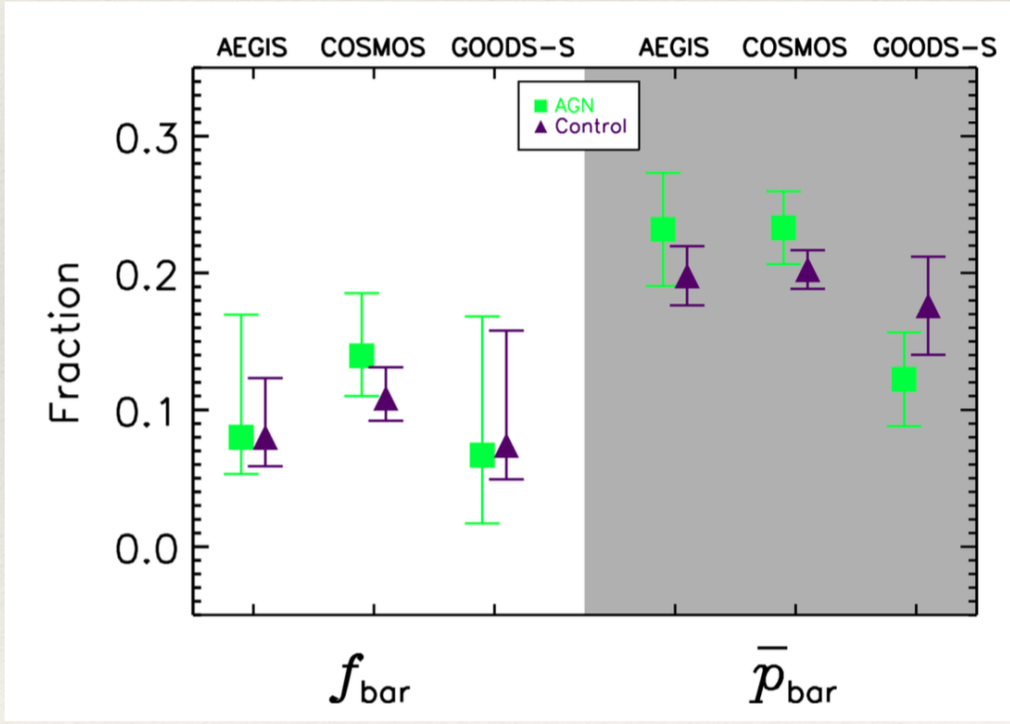
Bars

Inner gas fuels:

Circumnuclear starburst rings
(perhaps cyclically; Jogee, Scoville & Kenney 2005)

maybe not AGN?

NGC 1097



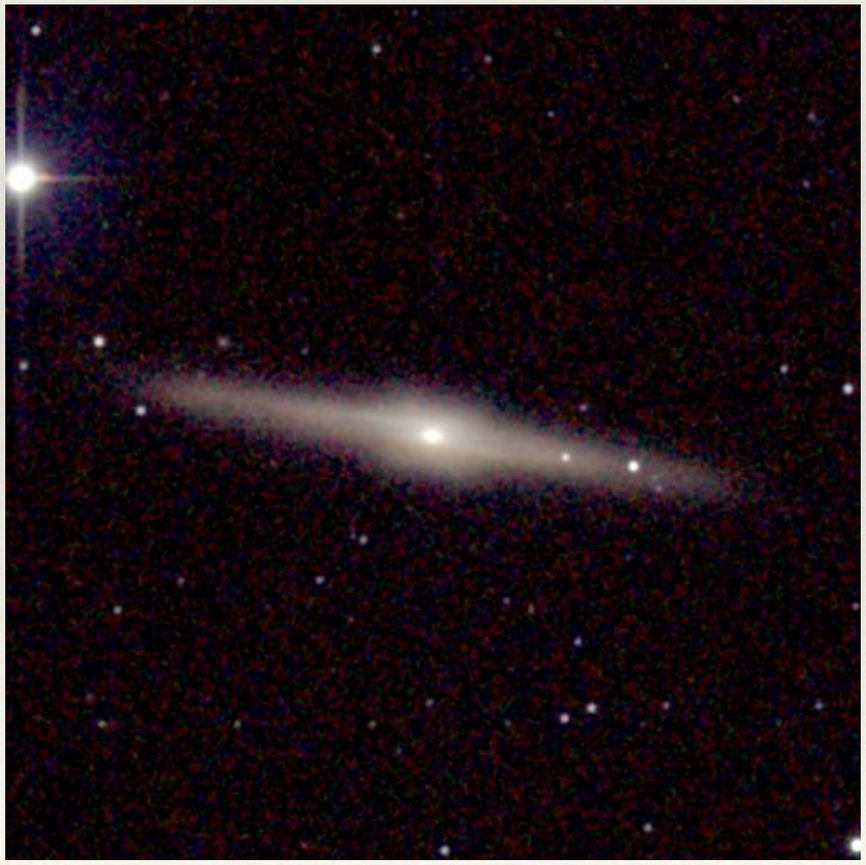
Cheung+ 2015
(also see Lee+ 2012, Galloway+ 2015)

Bars

May form “pseudobulges" through either:

Vertical heating instabilities

Bar buckling

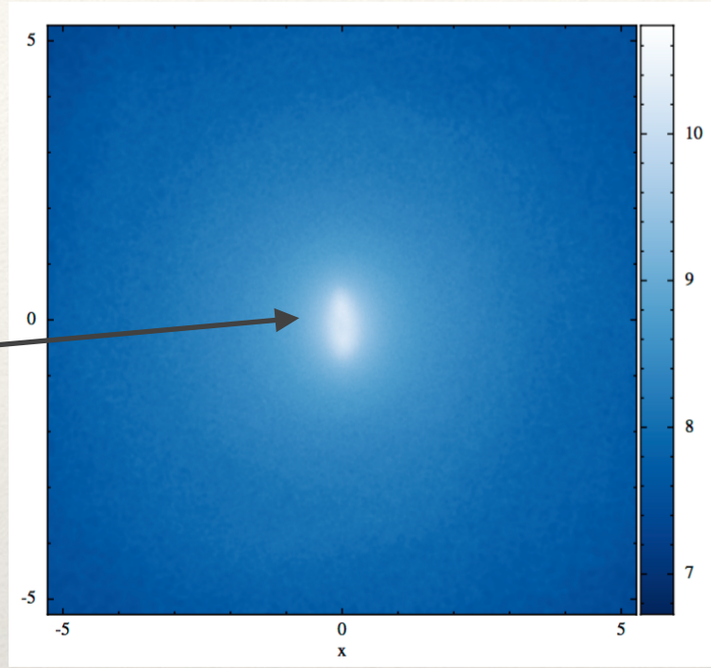


NGC 5746

Secular evolution from a bar in a cosmo/hydro simulation (ErisBH):
<u>Spinoso+ submitted</u>

z ~ 1.4: disk becomes bar unstable
z ~ 0.4: bar forms (maybe triggered by passing satellite), gas infall begins

stellar surface density

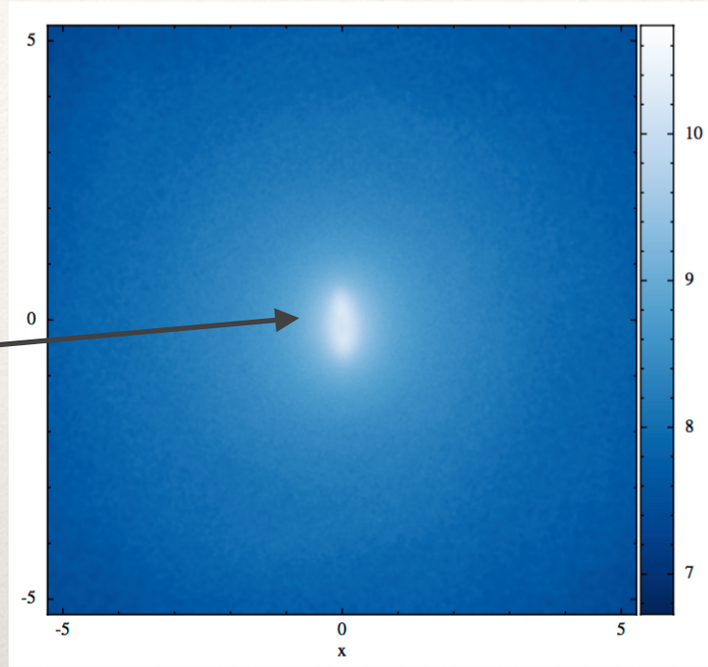


z = 0.42

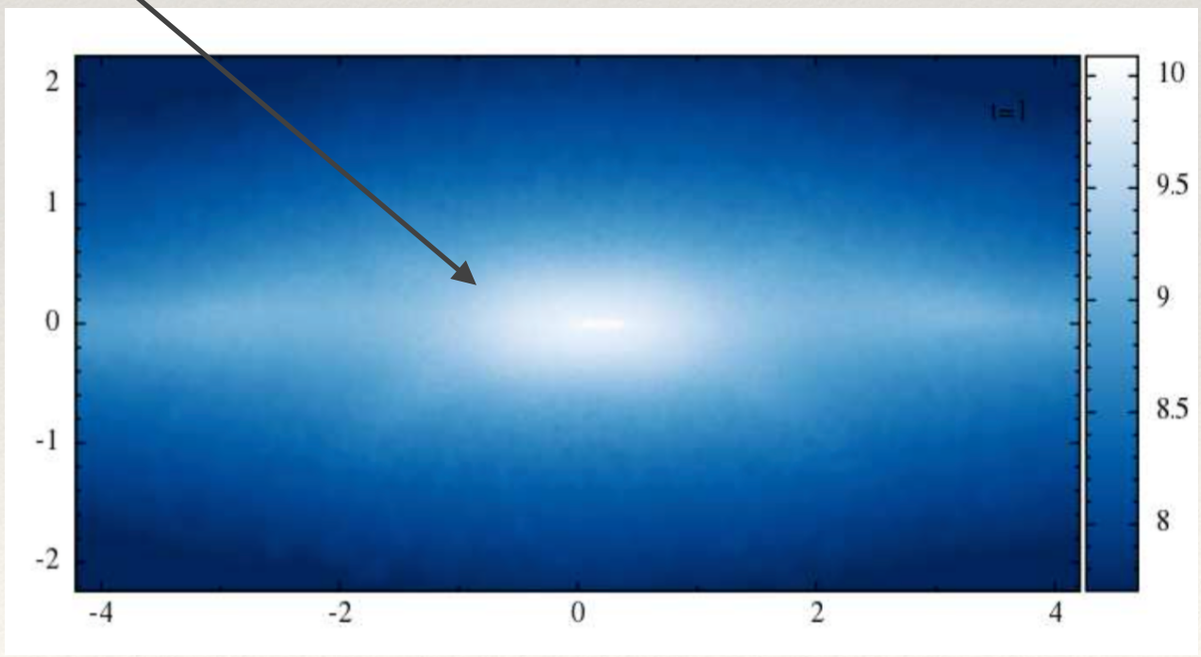
Secular evolution from a bar in a cosmo/hydro simulation (ErisBH):
<u>Spinoso+ submitted</u>

z ~ 1.4: disk becomes bar unstable
z ~ 0.4: bar forms (maybe triggered by passing satellite), gas infall begins
z ~ 0.1: bar buckles to form a pseudo bulge

stellar surface density



z = 0.42

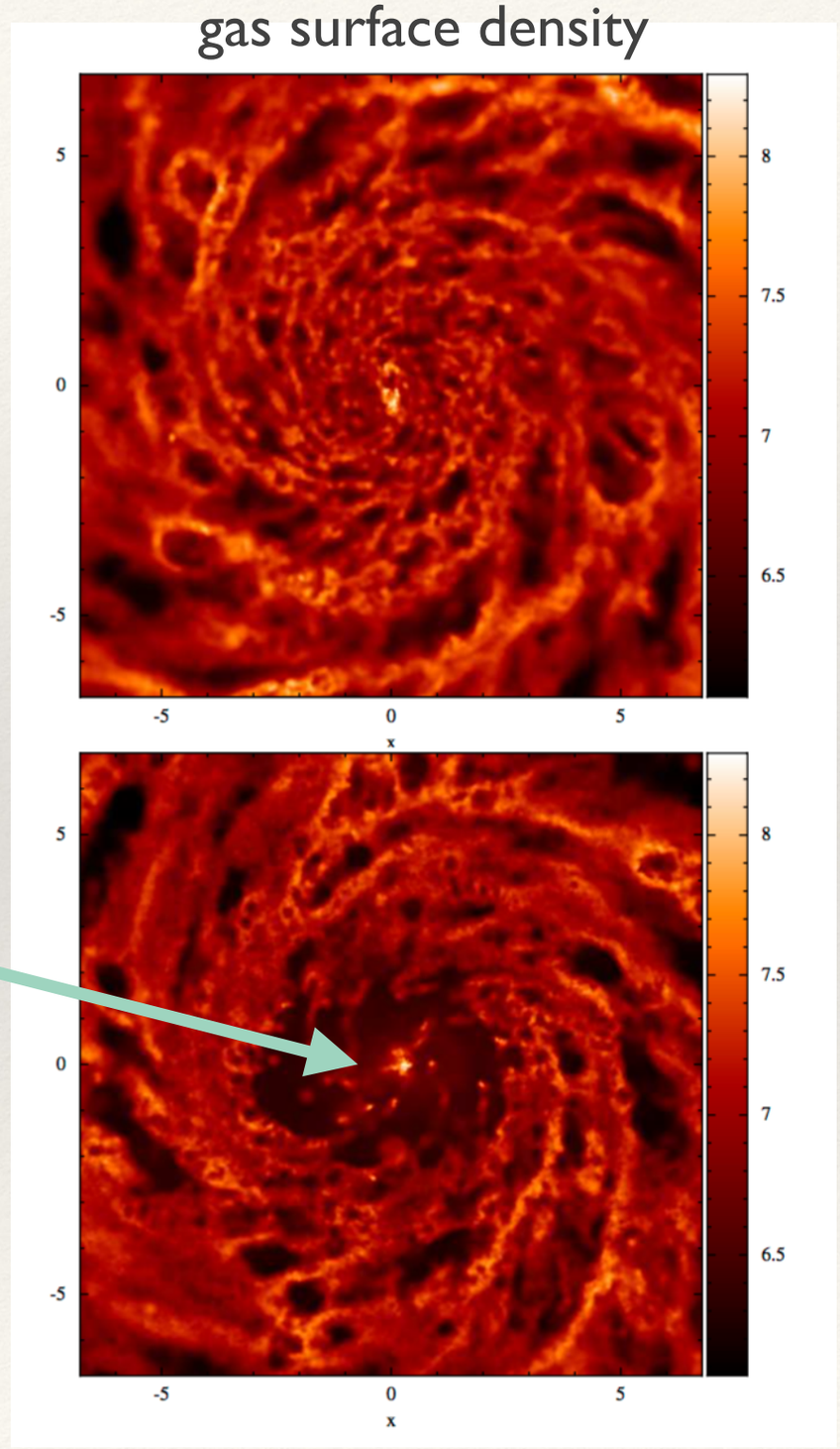


z = 0

Secular evolution from a bar in a cosmo/hydro simulation (ErisBH):
Spinoso+ submitted

z ~ 1.4: disk becomes bar unstable
z ~ 0.4: bar forms (maybe triggered by passing satellite), gas infall begins
z ~ 0.1: bar buckles to form a pseudo bulge

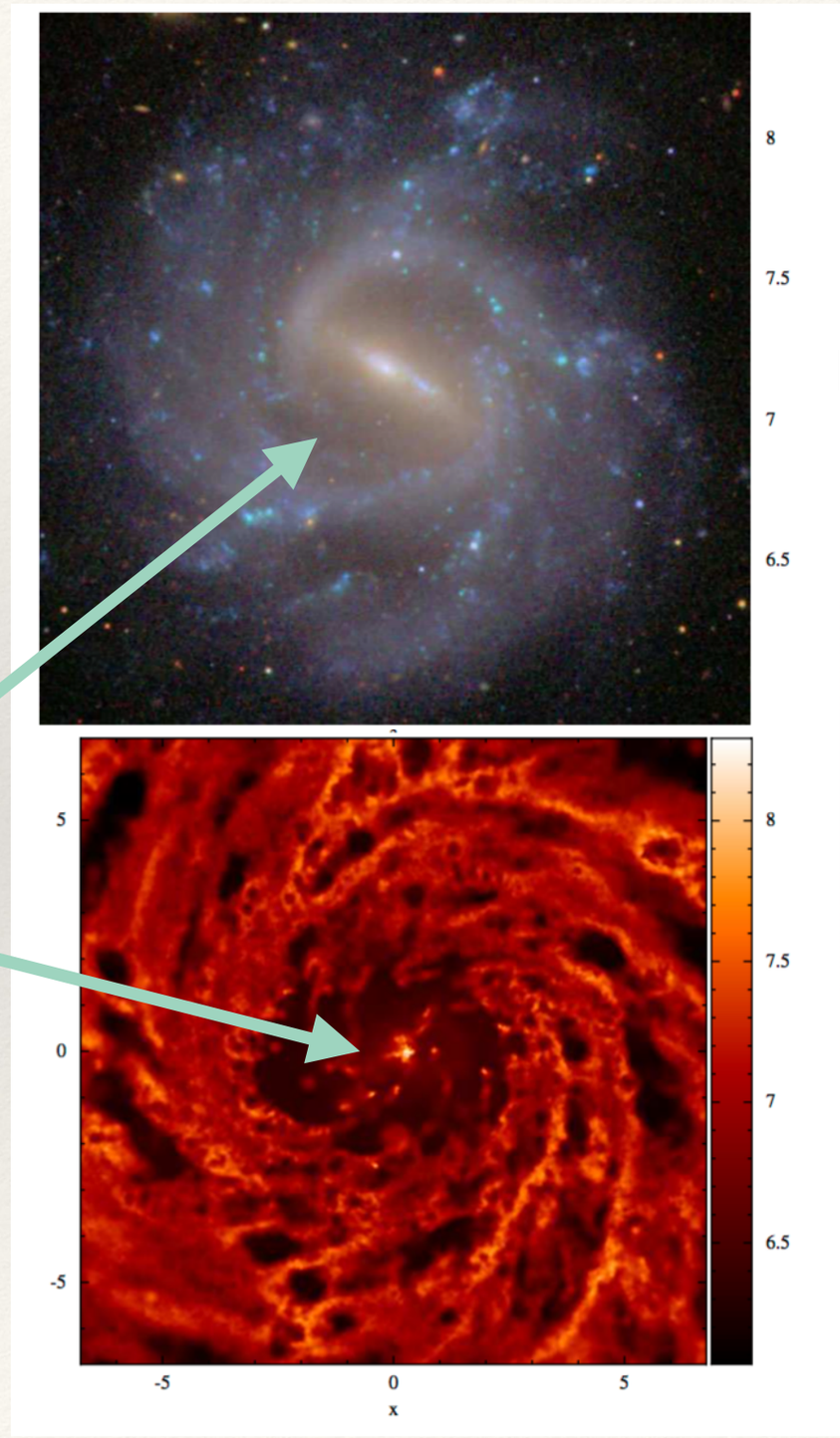
central 2 kpc ‘dead zone’ which is quenched due to lack of gas



z = 0.42

z = 0

Secular evolution from a bar in a cosmo/hydro simulation (ErisBH):
Spinoso+ submitted



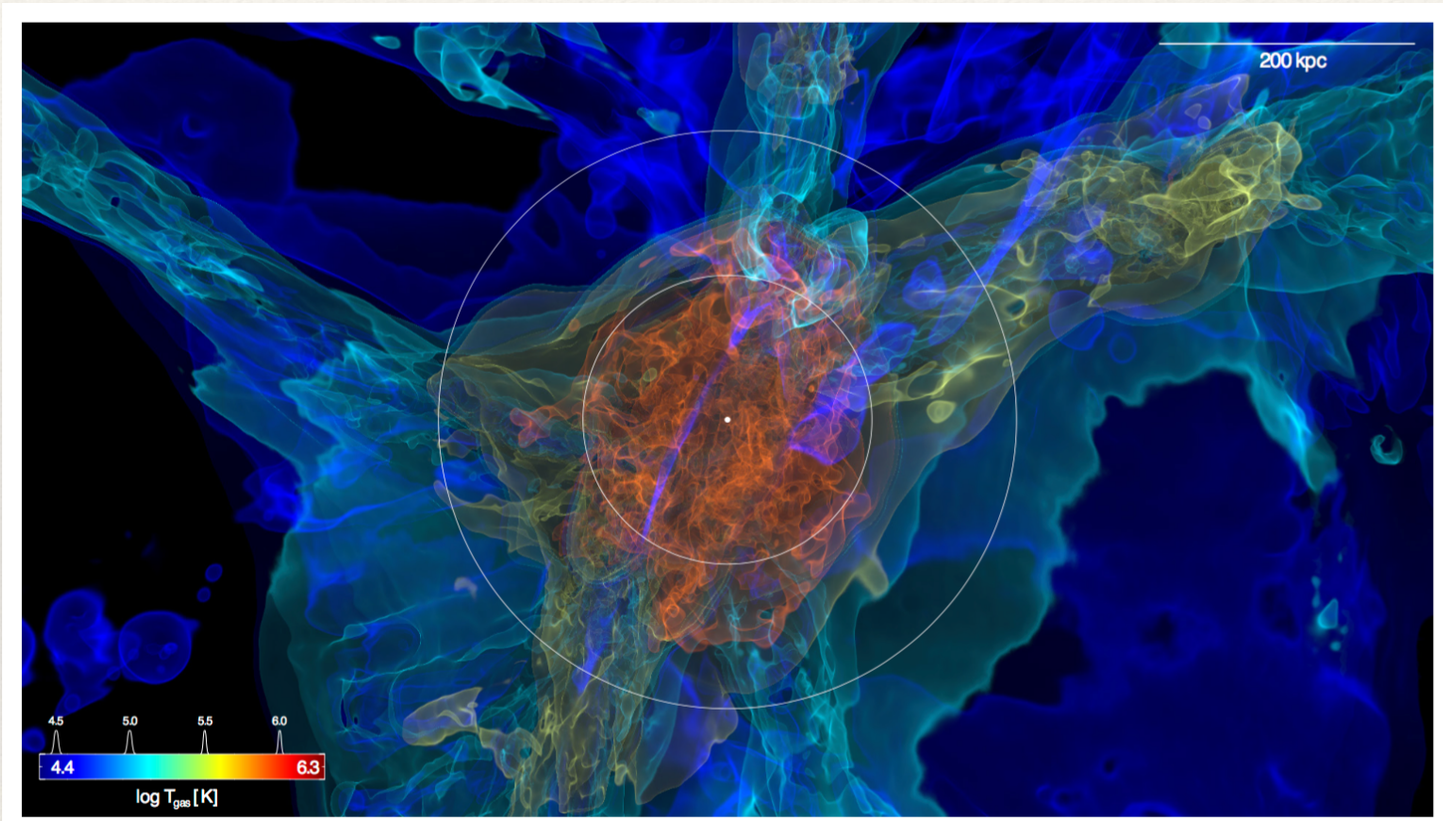
NGC 1073

central 2 kpc ‘dead zone’ which is quenched due to lack of gas

z = 0

Hot Halo Quenching

(aka: halo mass quenching, radio mode feedback)

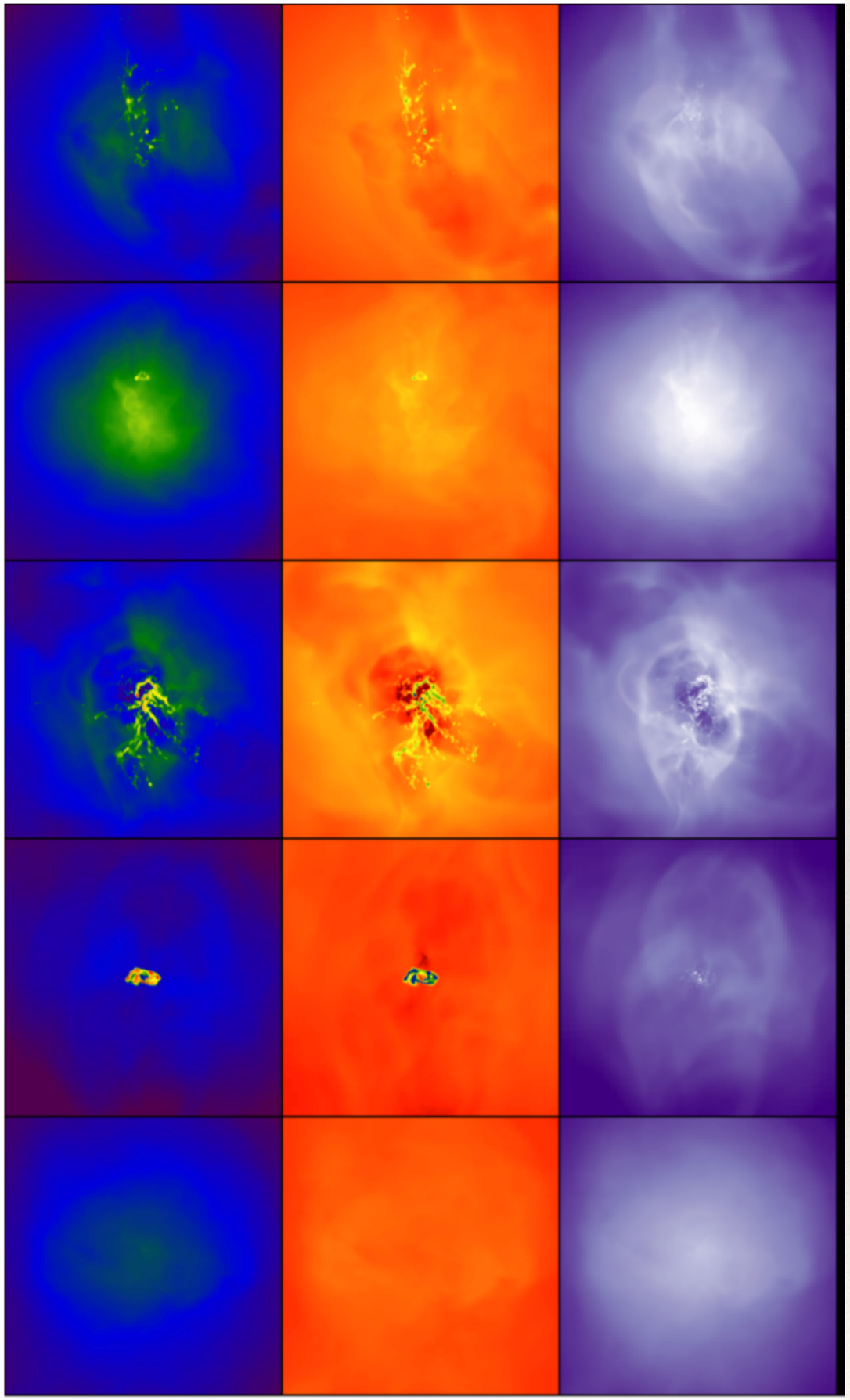


z = 2

Nelson+ 2015

Idea: above a certain halo mass (~10^{12} M_{sun}), accreting gas shock heats and joins a hot halo.

(Birnboim & Dekel 2003, Keres et al. 2005)



Do need (AGN) feedback to maintain hot halo and prevent cooling.

Li, Y. + 2015

Precipitation model: a small amount of gas cools in a cooling flow, feeding AGN, reheating halo back to equilibrium.
(Voit+ 2014)

Conclusions

Morphological quenching	Bars	Hot halo quenching
Observations: definitely occurs. Theory: shear most important (?)	Effective at quenching inner regions of spirals.	Hot halo can prevent cold gas accretion; cyclical AGN feedback may keep heated.