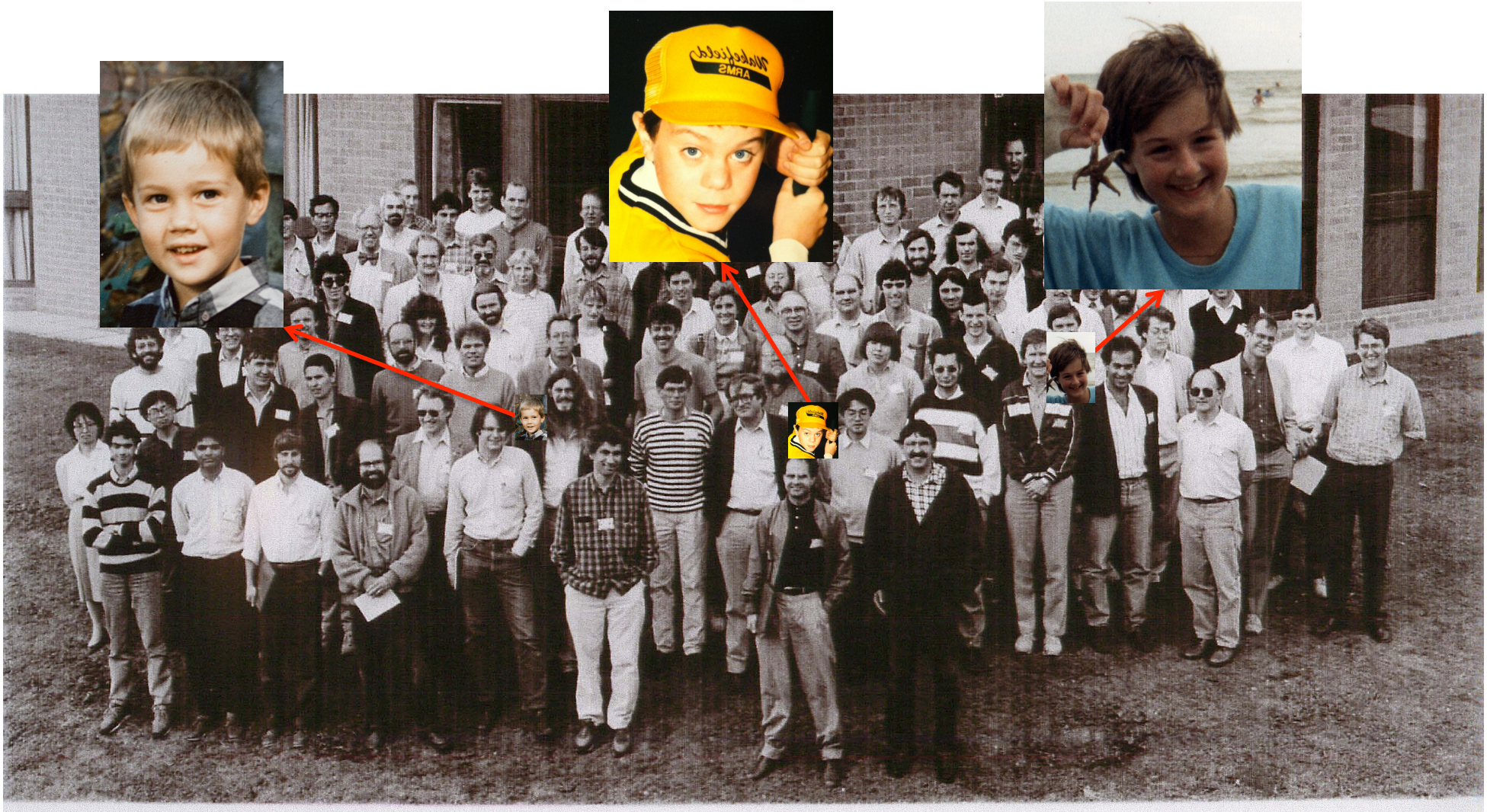


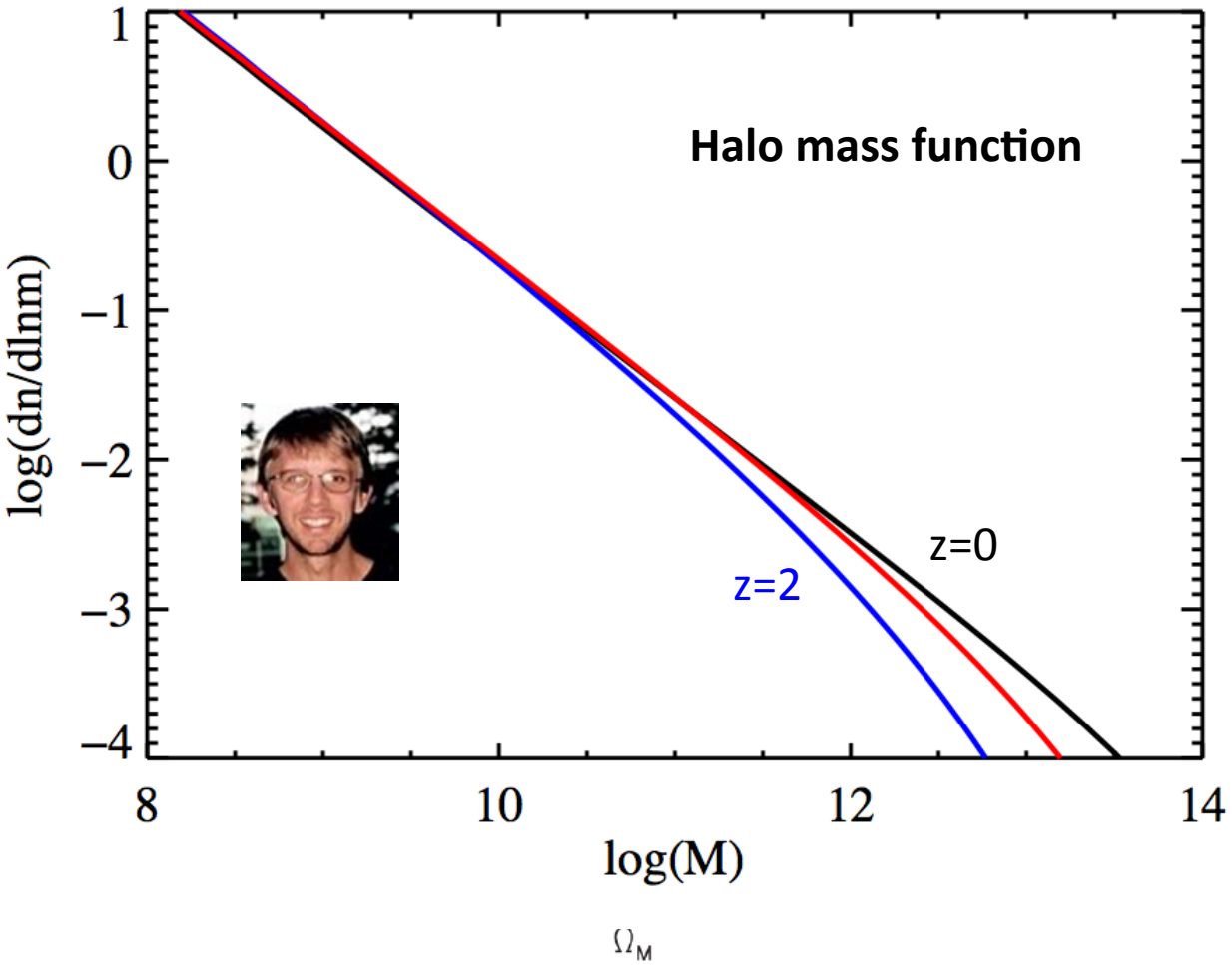
NATO ADVANCED RESEARCH WORKSHOP

"THE EPOCH OF GALAXY FORMATION"

UNIVERSITY OF DURHAM. U.K. JULY 18-22, 1988

“10 billion years ago things were the same”
- X. Prochaska

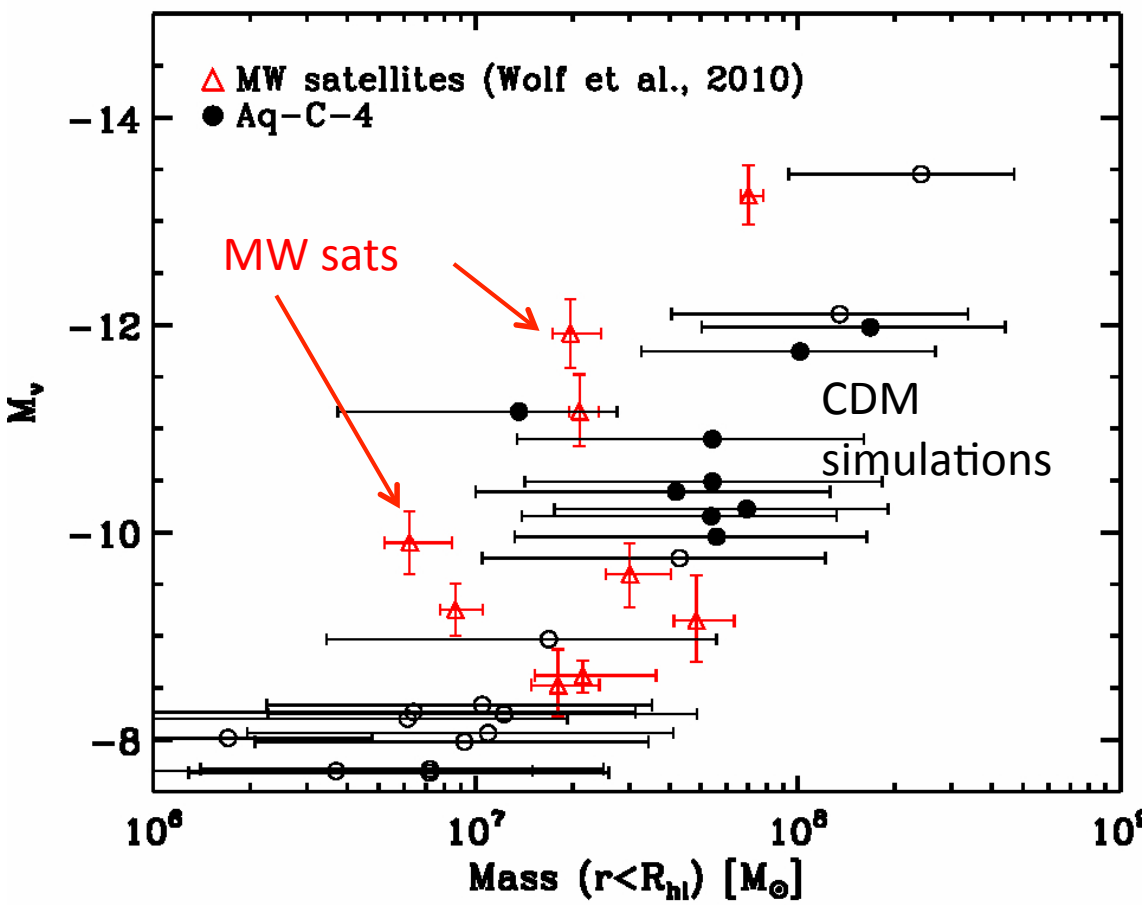
LCDM is correct



osmological N-body
mulations at ever higher
esolution and volume
Millennium (I,II,XXL)
Bolshoi

ark matter halos, merger
ees, etc.
he underlying structure,
nd its evolution, is known

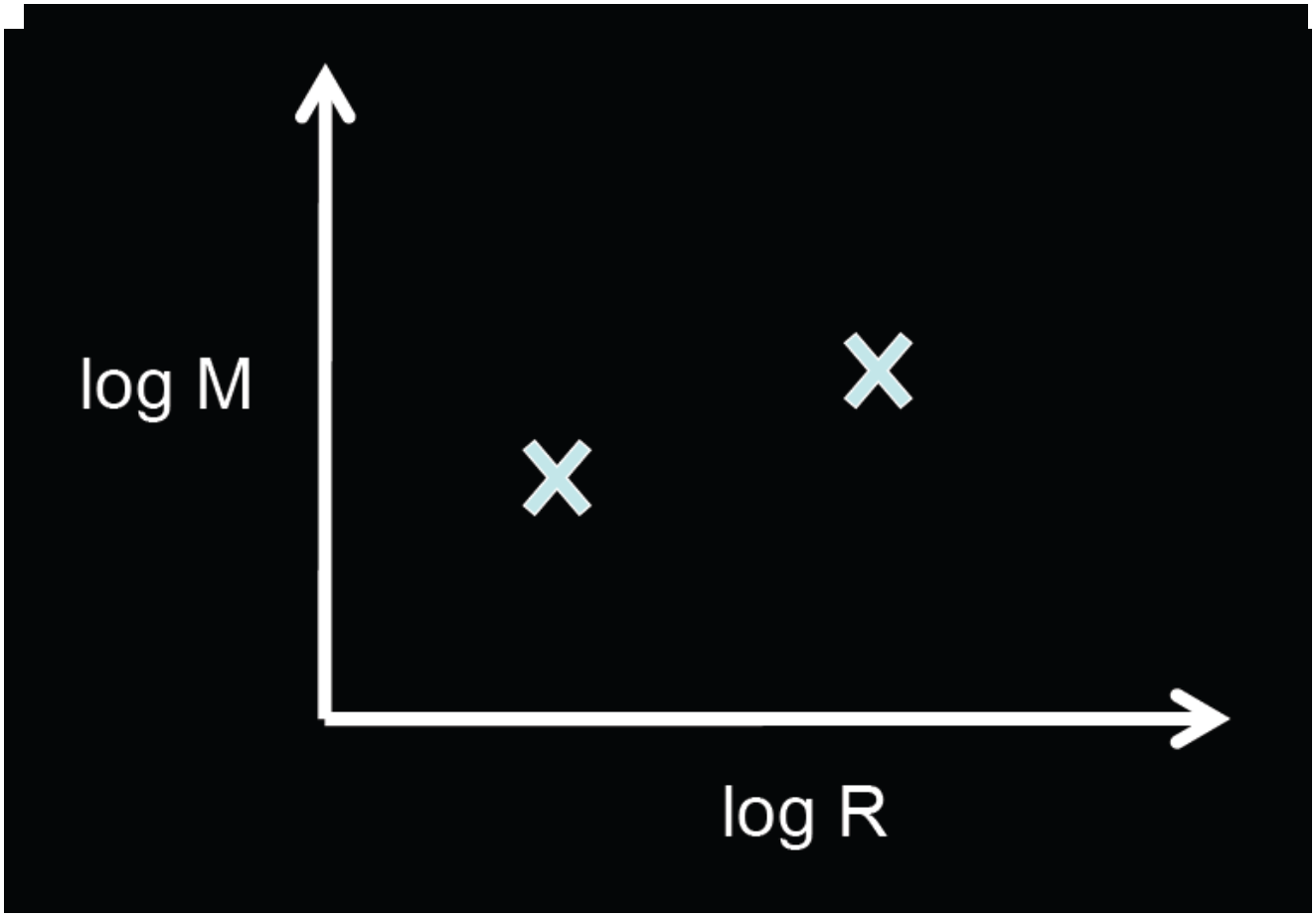
Or not?



Carlos:
"CDM rejected at 93.6% confidence level"

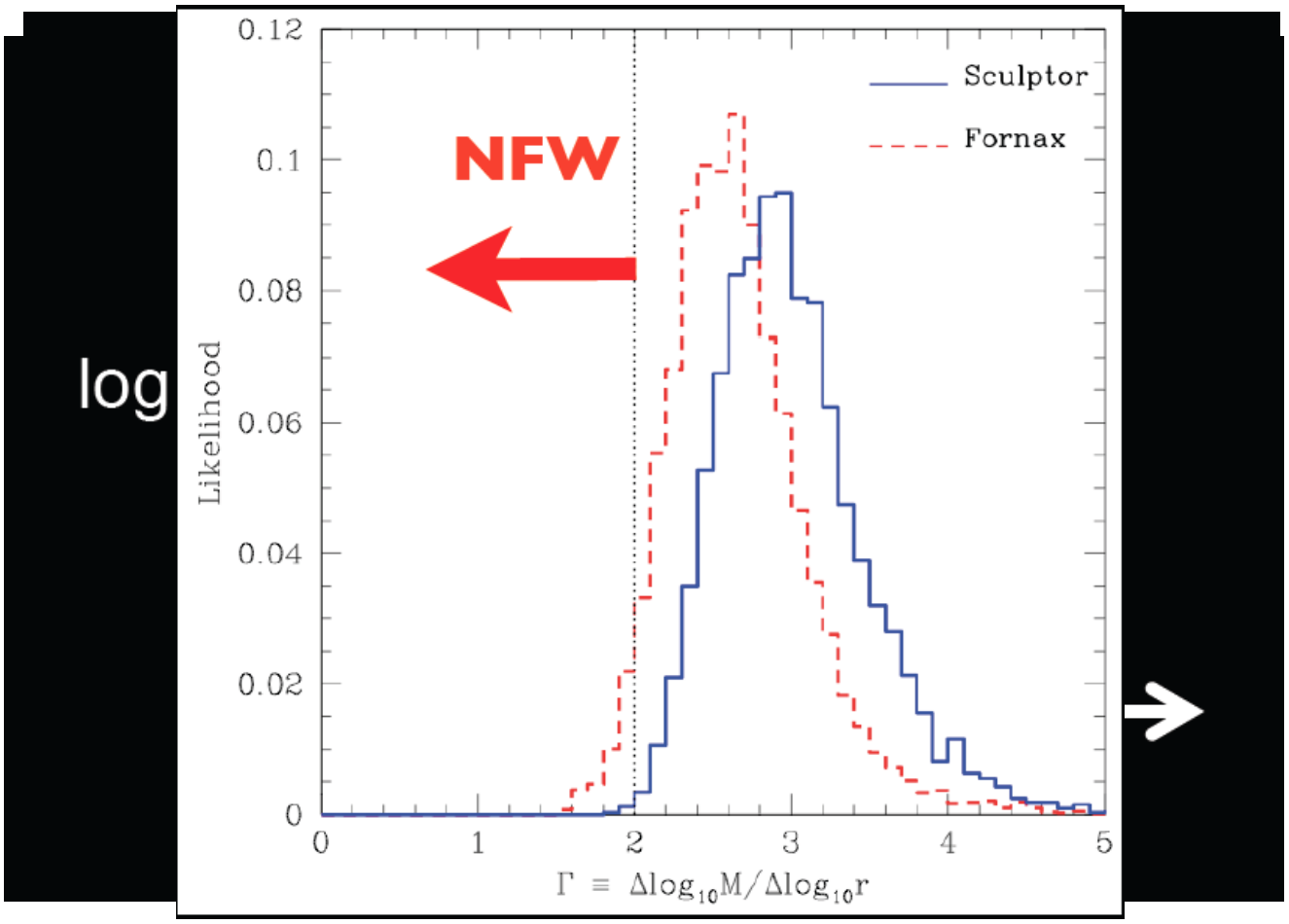
Parry, Eke & Frenk '11

DM profiles in dwarf gals



Walker & Penarrubia 2011

DM profiles in dwarf gals

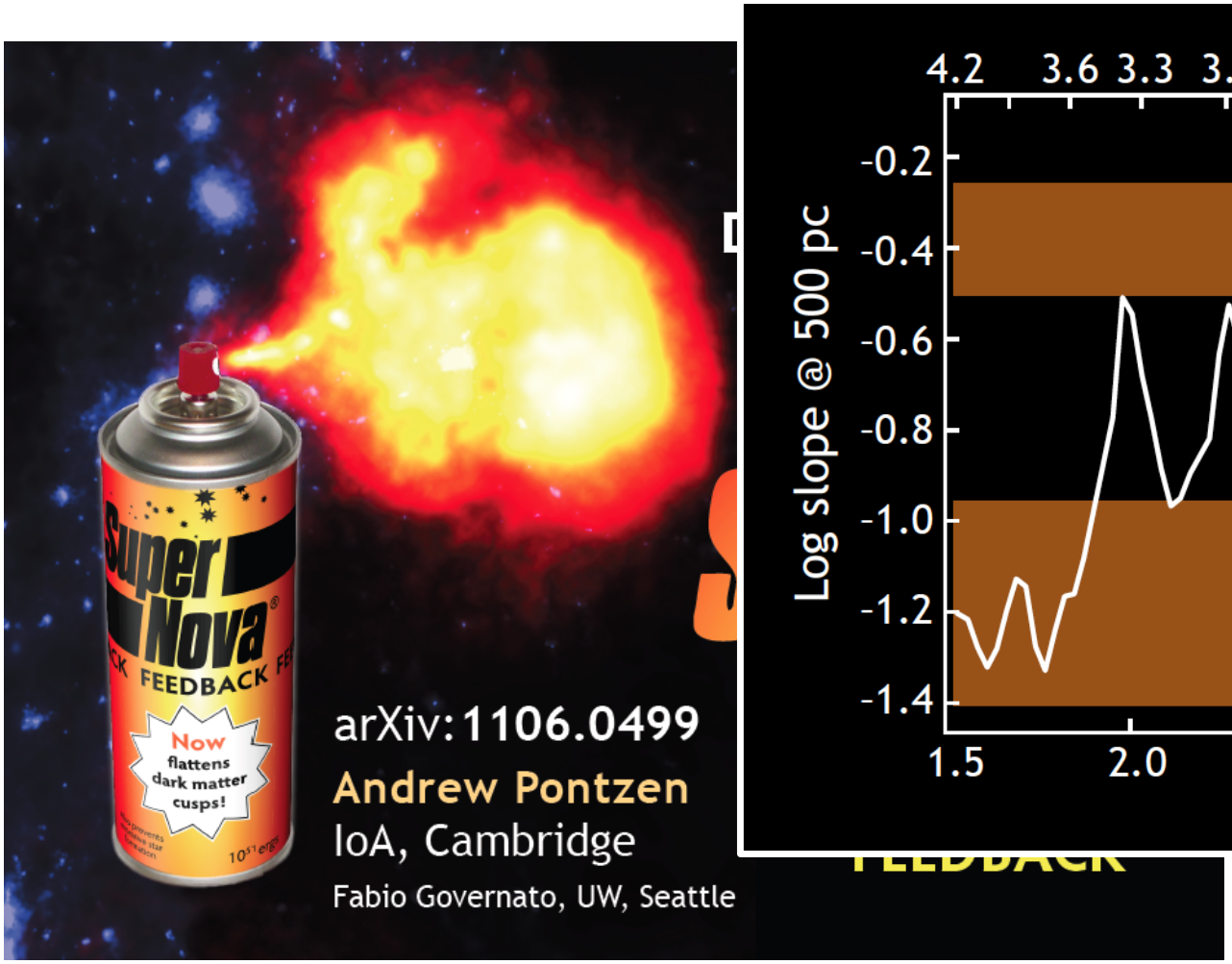


Walker & Penarrubia 2011

cusps ⟶ cores


FLATTENING
DARK MATTER
CUSPS
WITH
Super Nova®
FEEDBACK
Super Nova®
FEEDBACK
Now
flattens
dark matter
cusps!
arXiv:1106.0499
Andrew Pontzen
IoA, Cambridge
Fabio Governato, UW, Seattle

cusps ⟶ cores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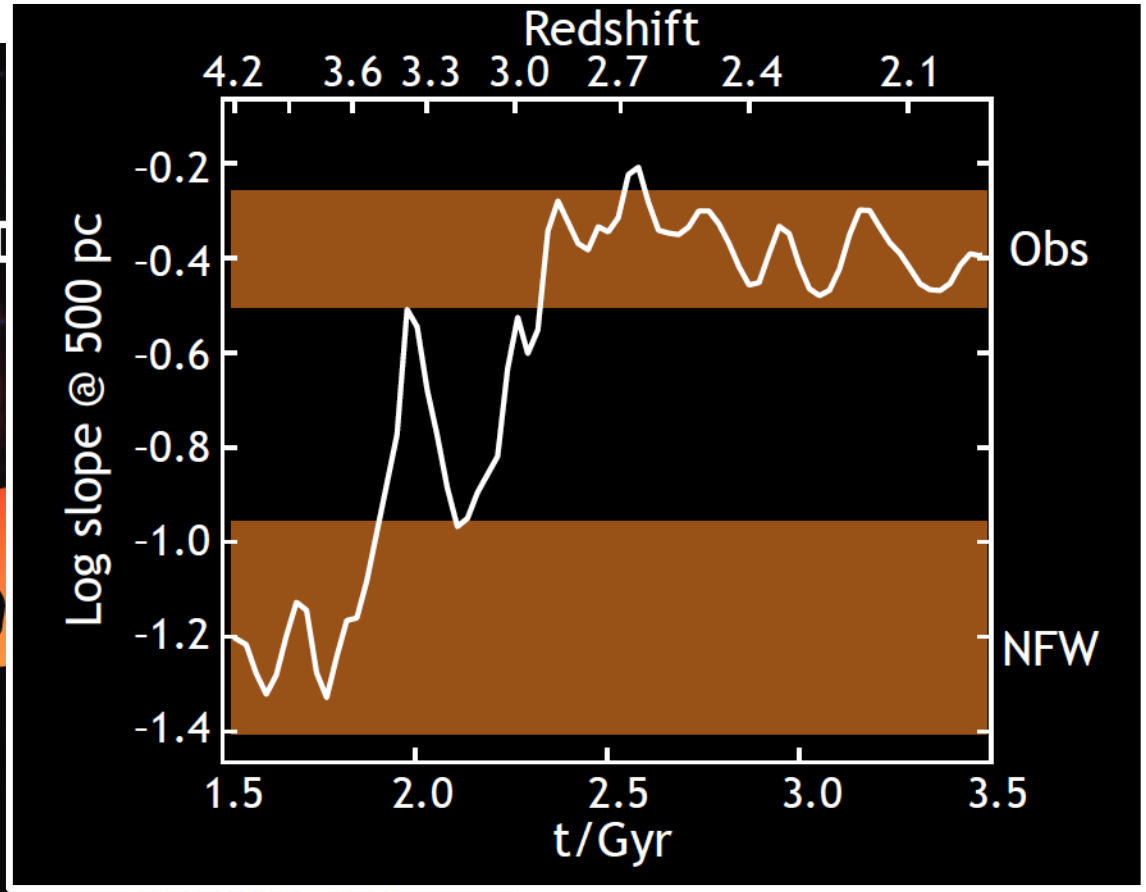
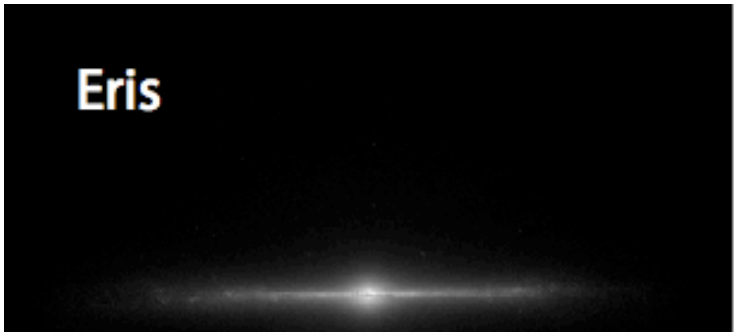
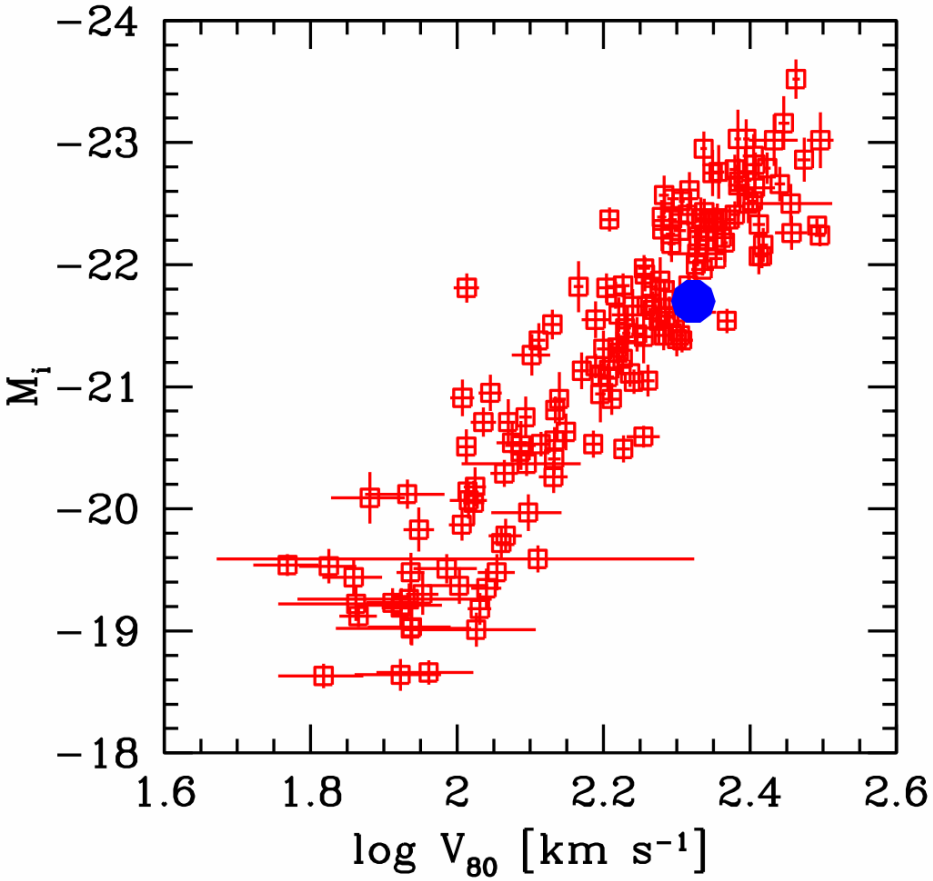
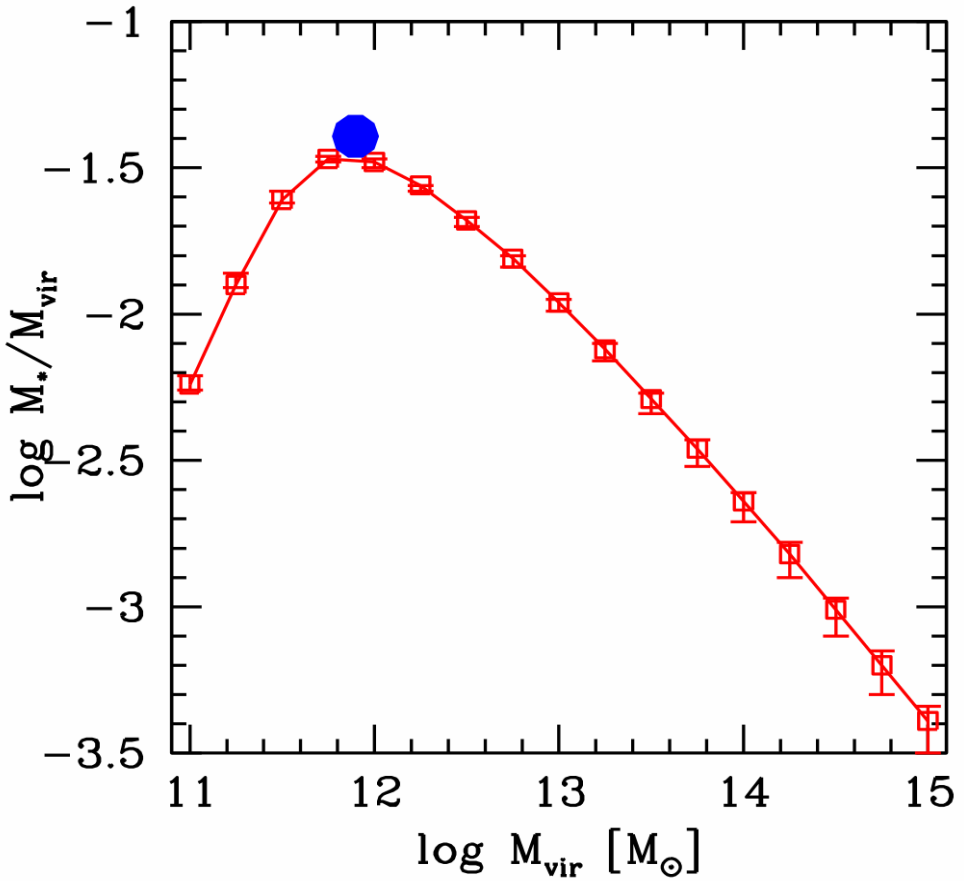

Redshift
4.2
3.6
3.3
3.0
2.7
2.4
2.1
Log slope @ 500 pc
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
Obs
NFW
1.5
2.0
2.5
3.0
3.5
t/Gyr

forming bulge-less galaxies



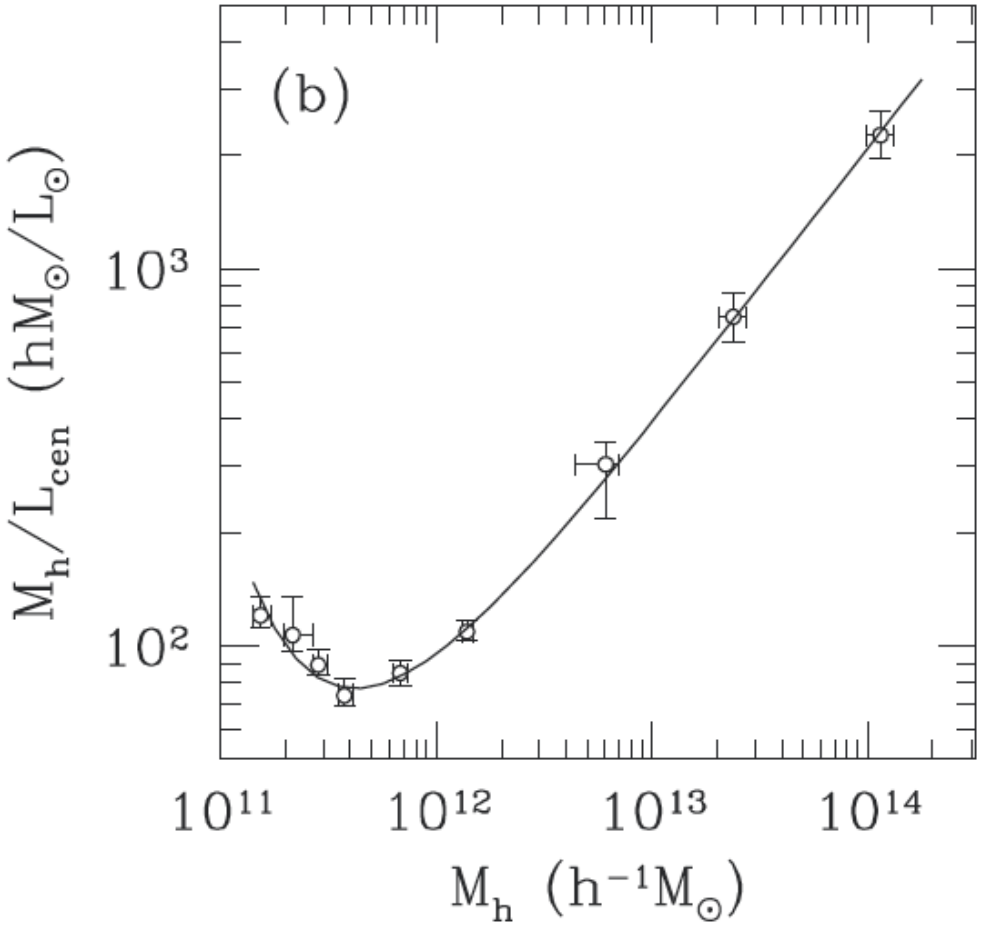
Lucio Mayer, Javiera Guedes
(also Hopkins' talk)





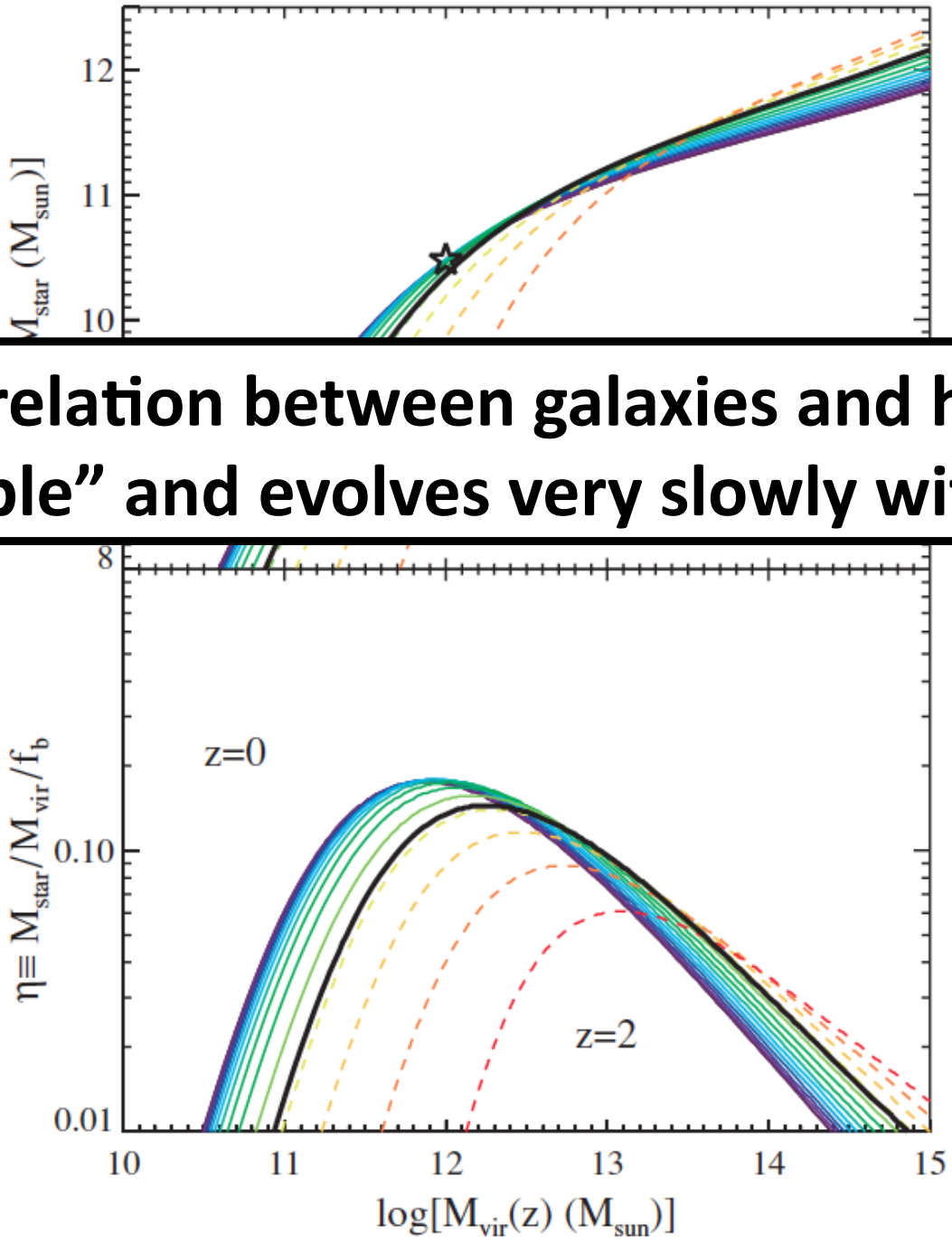
Galaxies reside in DM halos

- Lots of work establishing this relation
- Talks by Weinberg, Hudson, Primack, Kauffmann, White, etc.



Zehavi, Zheng, Weinberg et al. 2011

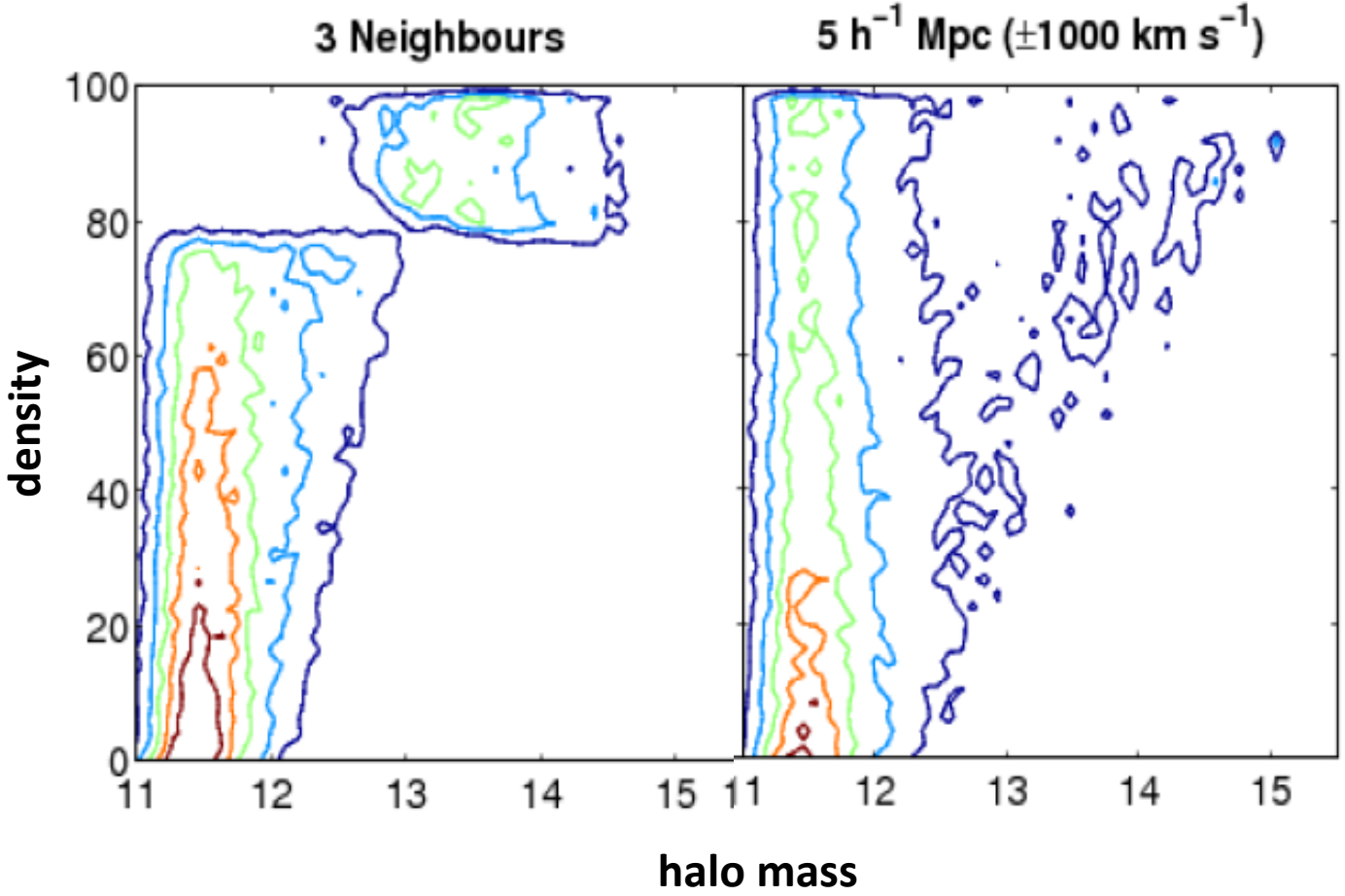
The relation between galaxies and halos is "simple" and evolves very slowly with time



See also Guo et al. 2011, Simon White's talk

Conroy & Wechsler 2009

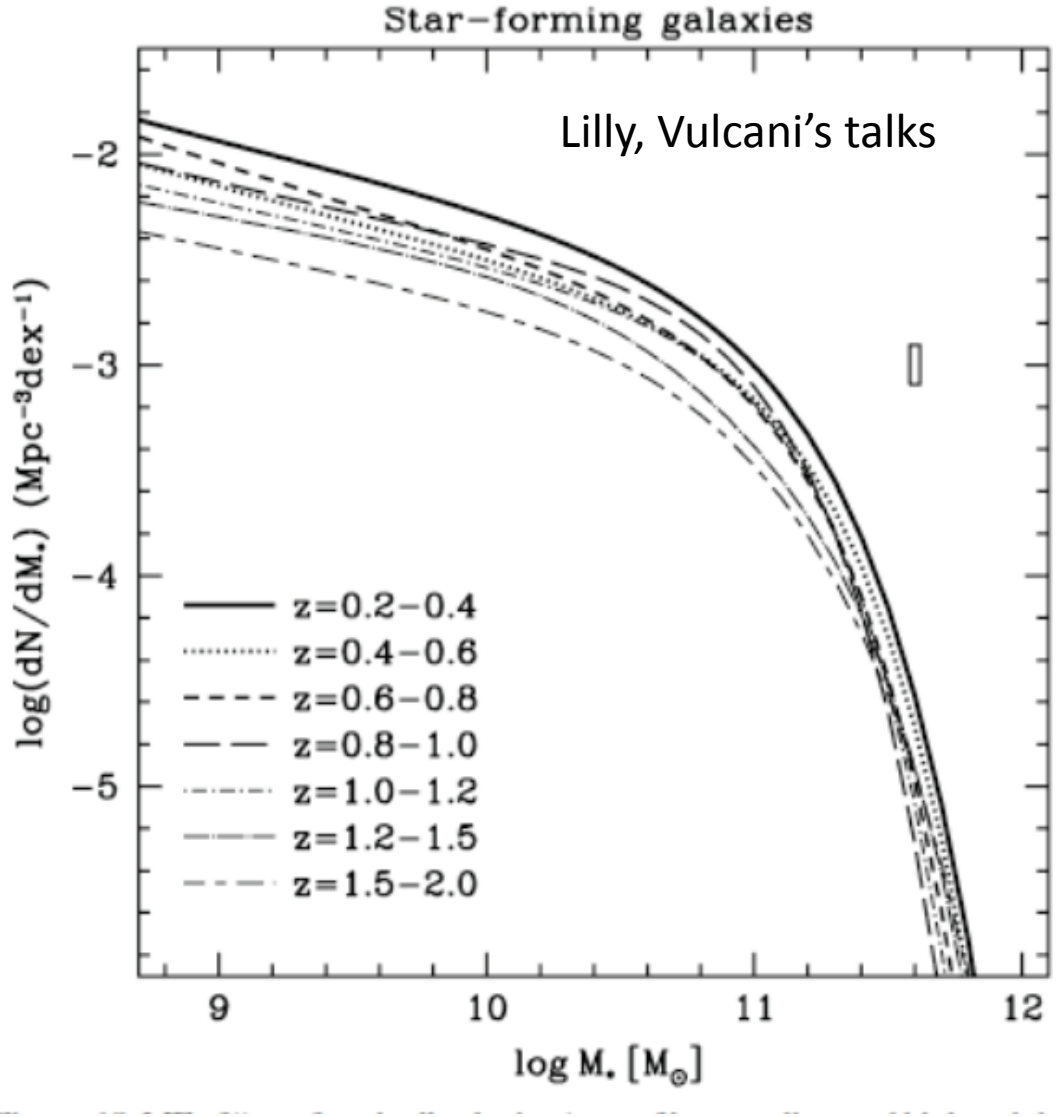
“Environment” -> halos



Muldrew, Croton, Skibba, Pearce, et al. 2011

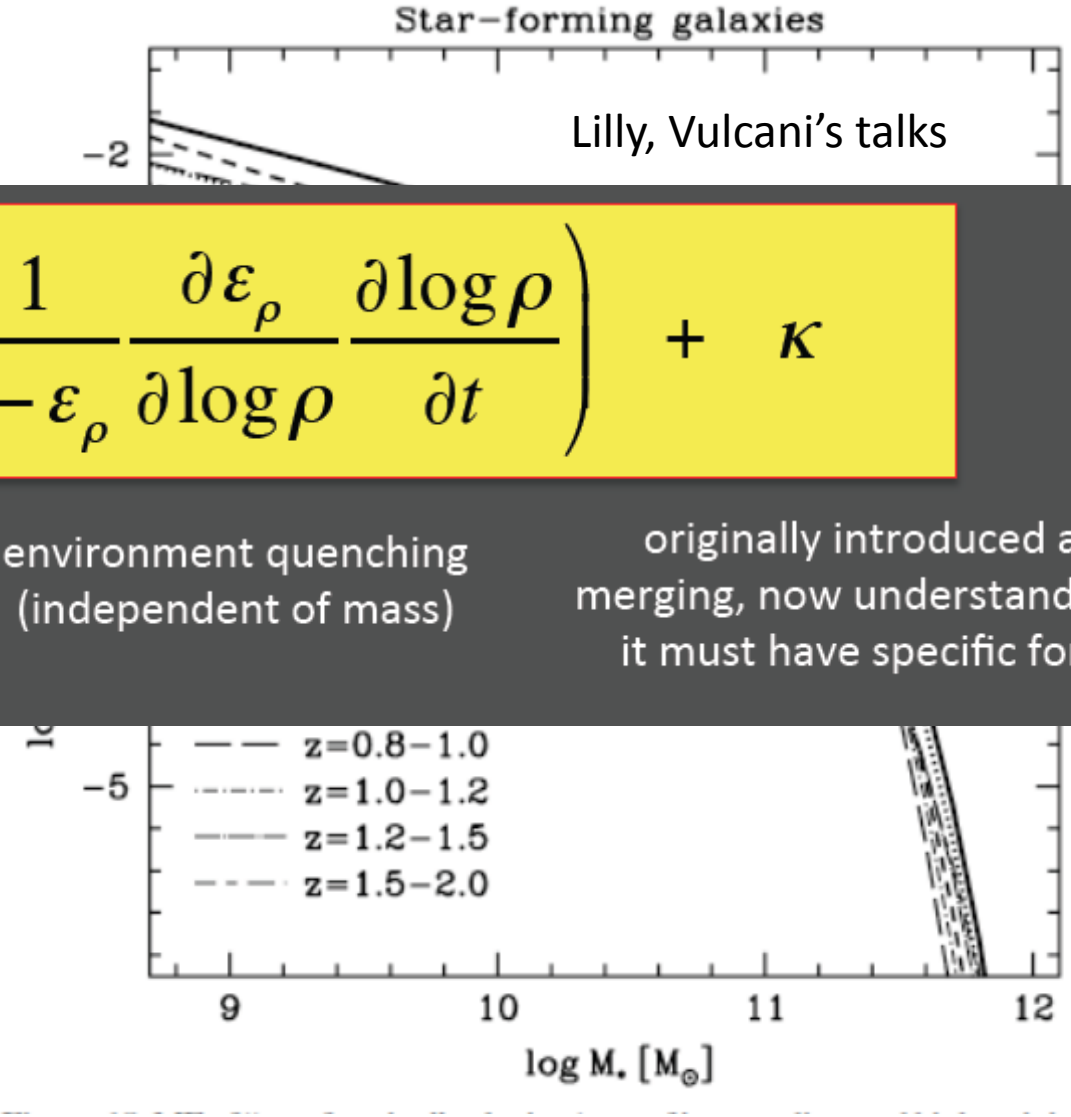
The Continuity Equation

- Lilly's talk (and Peng's)



The Continuity Equation

- Lilly's talk (and Peng's)



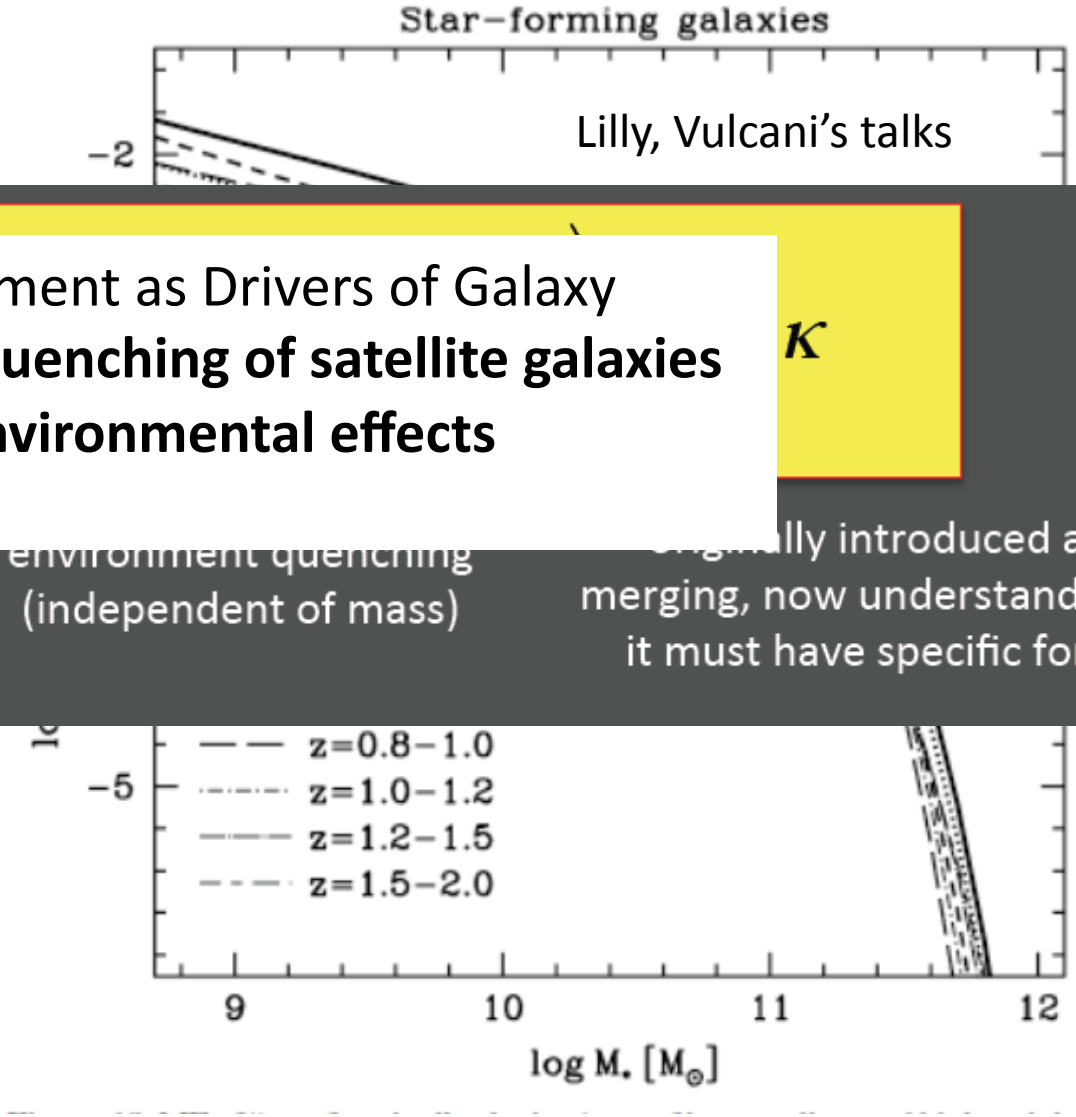
Lilly, Vulcani's talks

$$\eta = \mu\, SFR + \left(\frac{1}{1-\varepsilon_\rho} \frac{\partial \varepsilon_\rho}{\partial \log \rho} \frac{\partial \log \rho}{\partial t} \right) + \kappa$$

overall quenching rate (time^{-1})	mass quenching (independent of environment)	environment quenching (independent of mass)	originally introduced as merging, now understand that it must have specific form

The Continuity Equation

- Lilly's talk (and Peng's)



Lilly, Vulcani's talks

$\eta =$ κ

Mass and Environment as Drivers of Galaxy Evolution II: **The quenching of satellite galaxies as the origin of environmental effects**
- Peng et al. 2011

overall quenching rate (time^{-1})

(independent of environment)

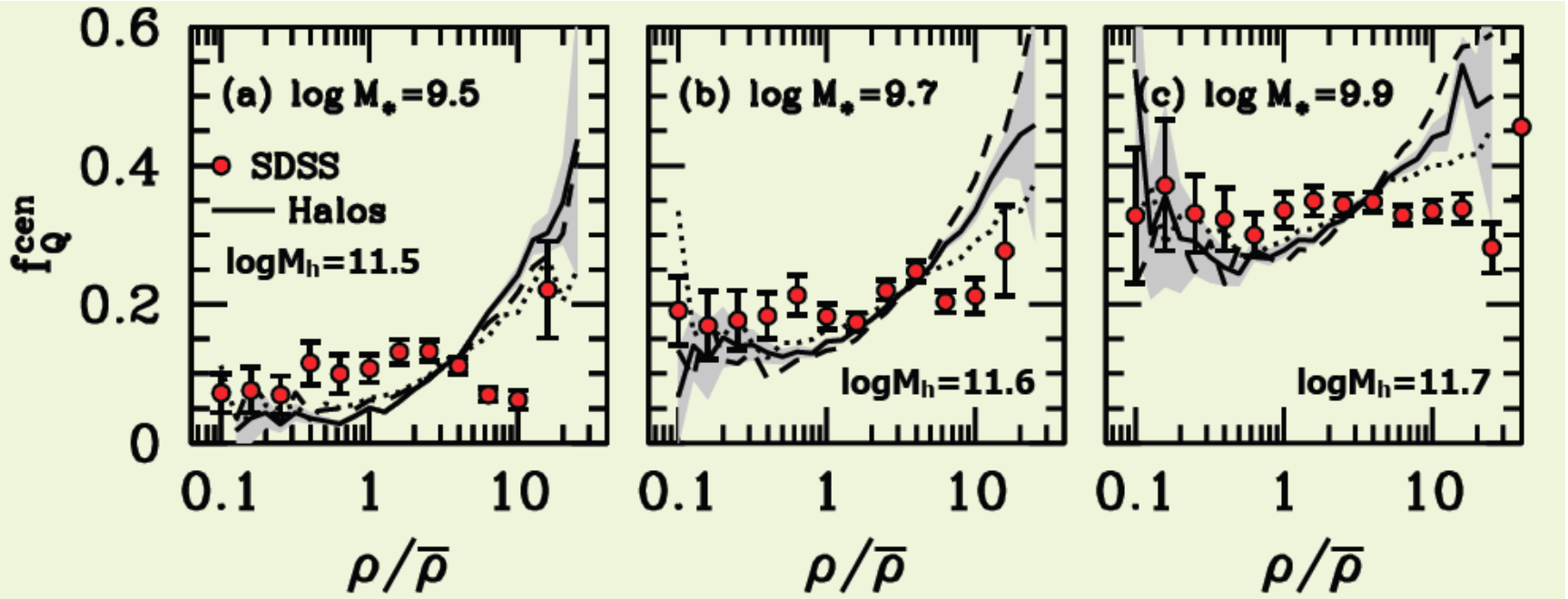
environment quenching (independent of mass)

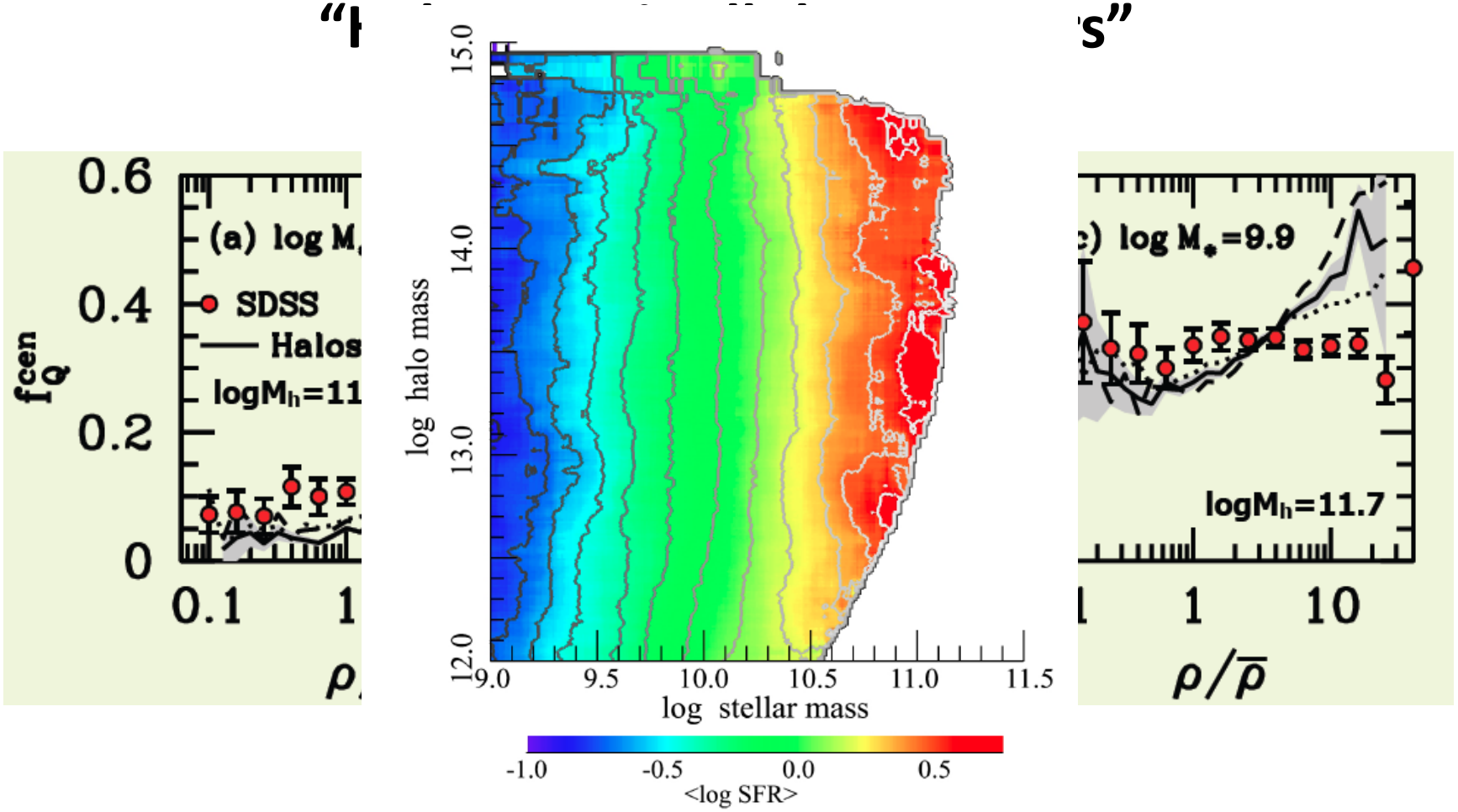
lly introduced as merging, now understand that it must have specific form

“We don't know what mass quenching is, but at least we identify it as a word”

- Simon Lilly

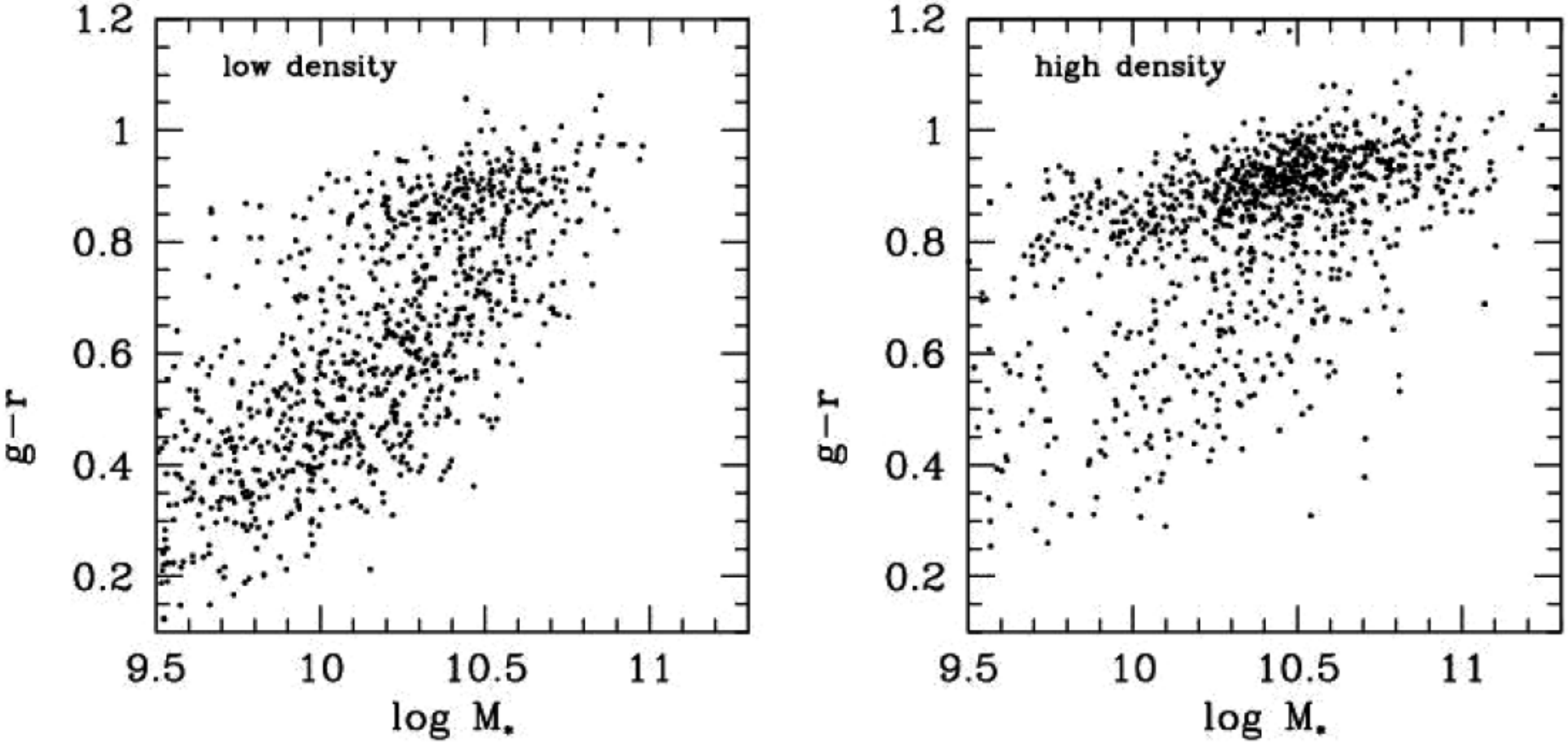
“Halo mass is all that matters”
- Jeremy Tinker





“Not even halo mass matters”

- Yingjie Peng (also Andrew Wetzel’s poster)

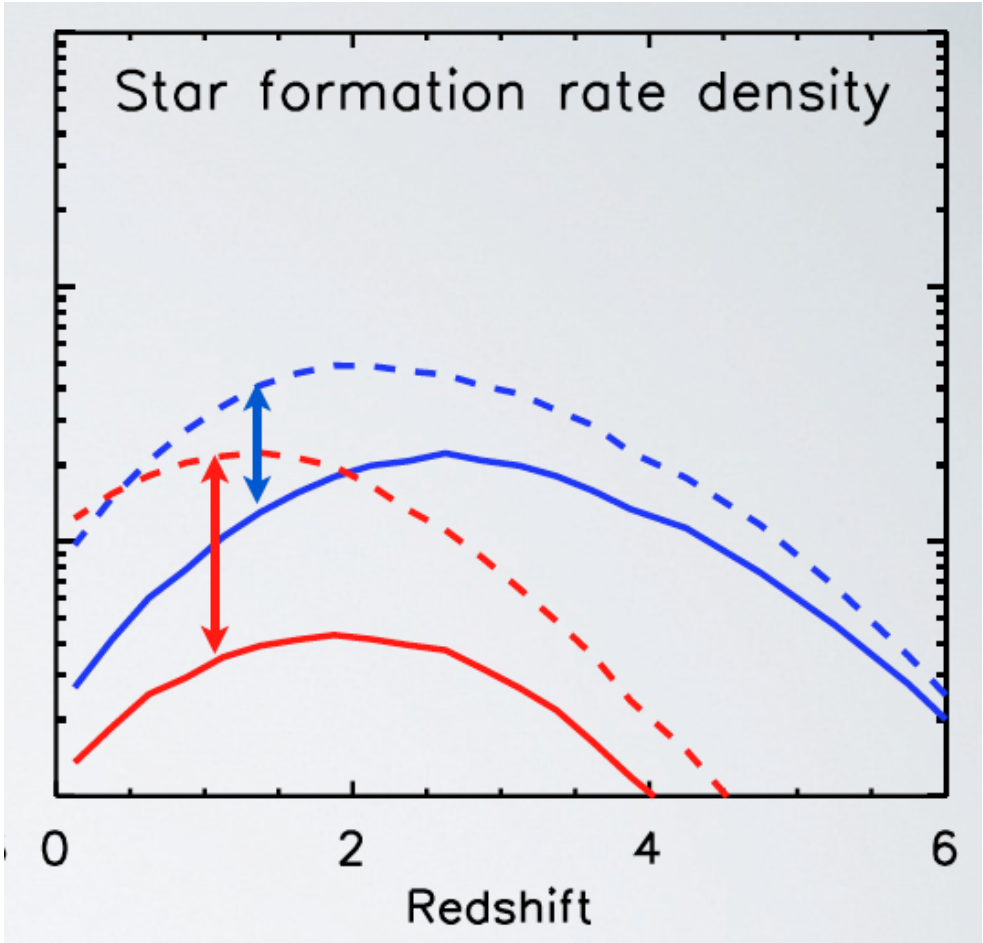


Kauffmann et al 2004

Evolution in cosmic SFR density

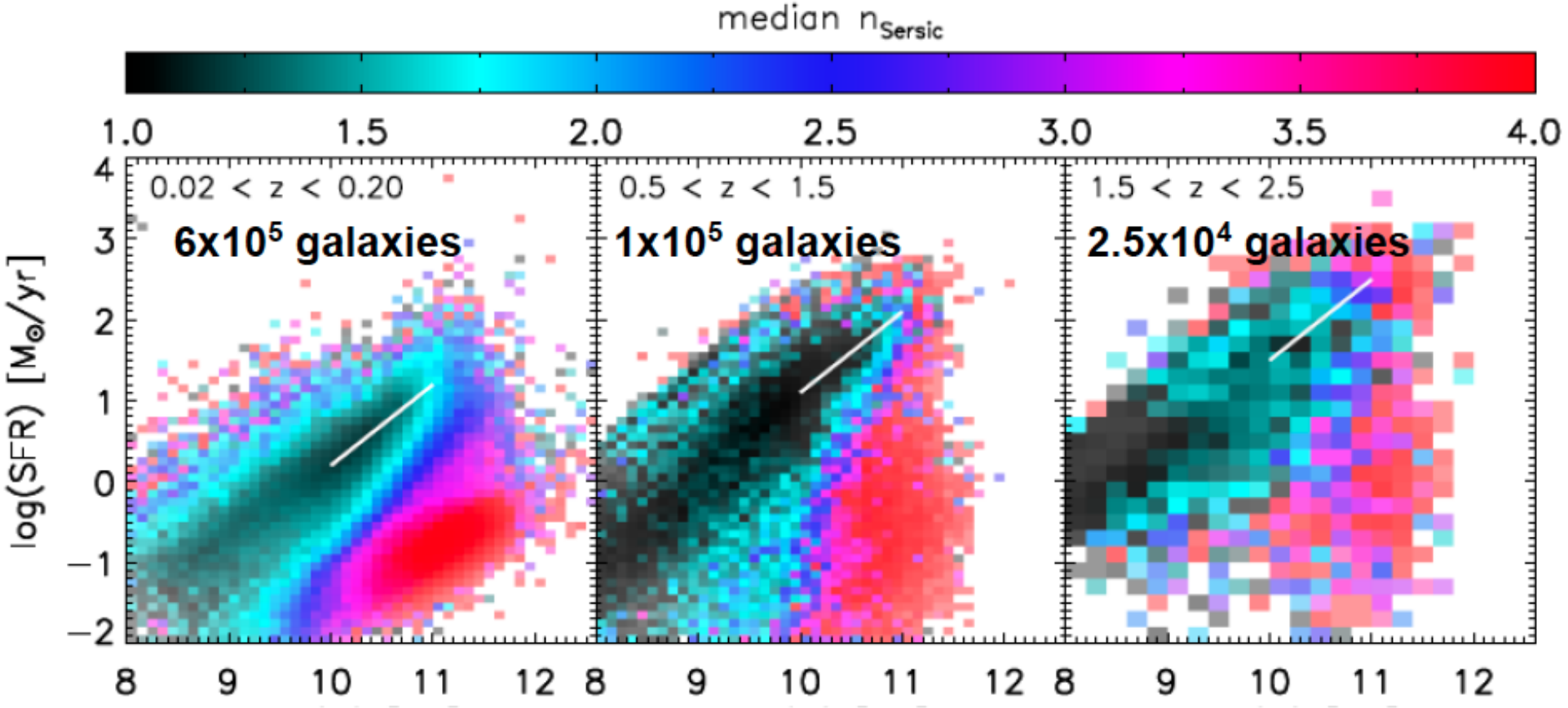
Van de Voort, Shaye

Driven by cosmic gas accretion onto the halo *and* AGN feedback



SF “main sequence”

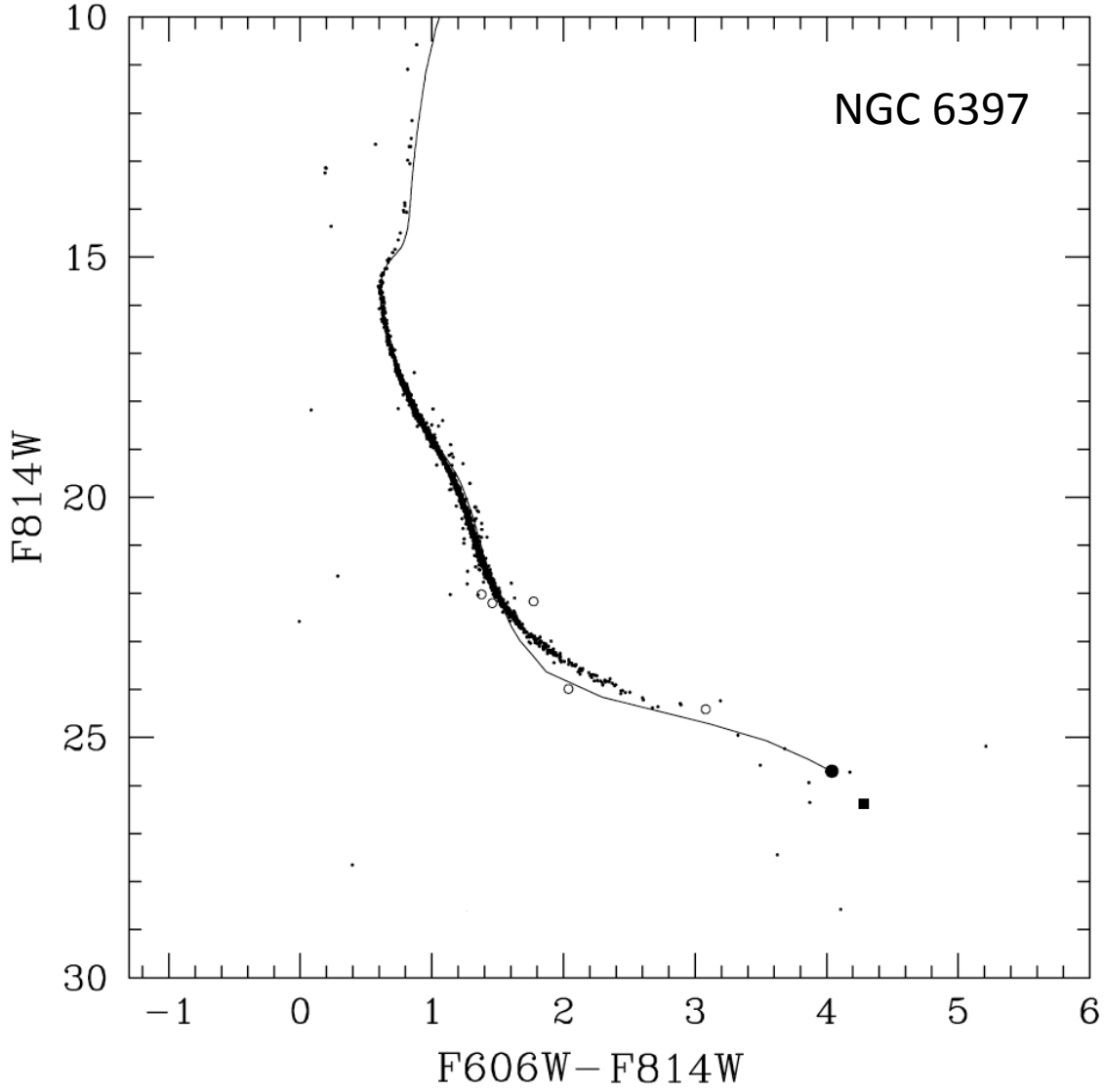
Elbaz, Genzel, Wuyts



Brinchmann et al. 2004
Daddi et al. 2005
Noeske et al. 2007

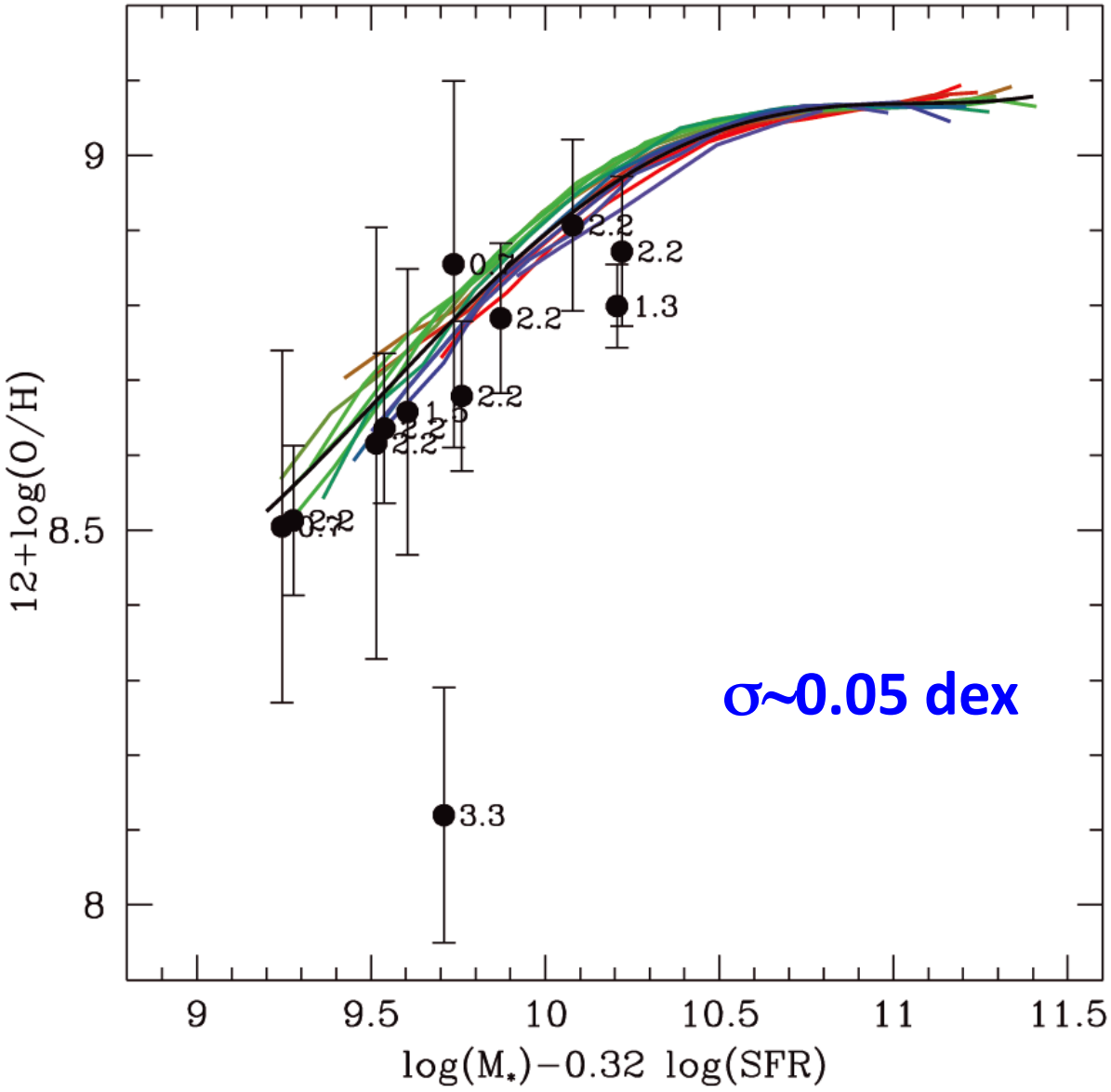
Wuyts et al. 2011

The *real* main sequence



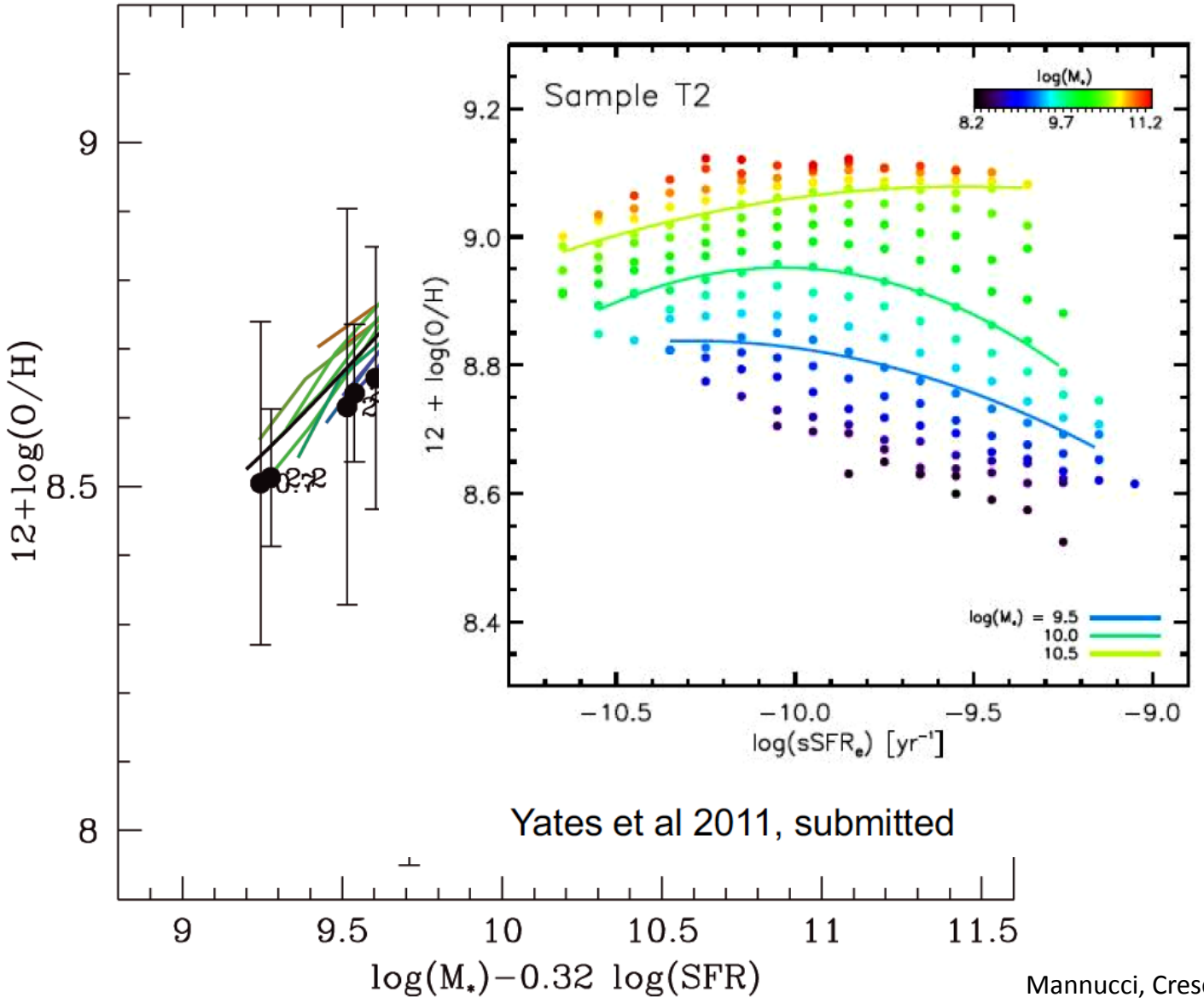
Richer et al. 2008

SFR-Z-Mass

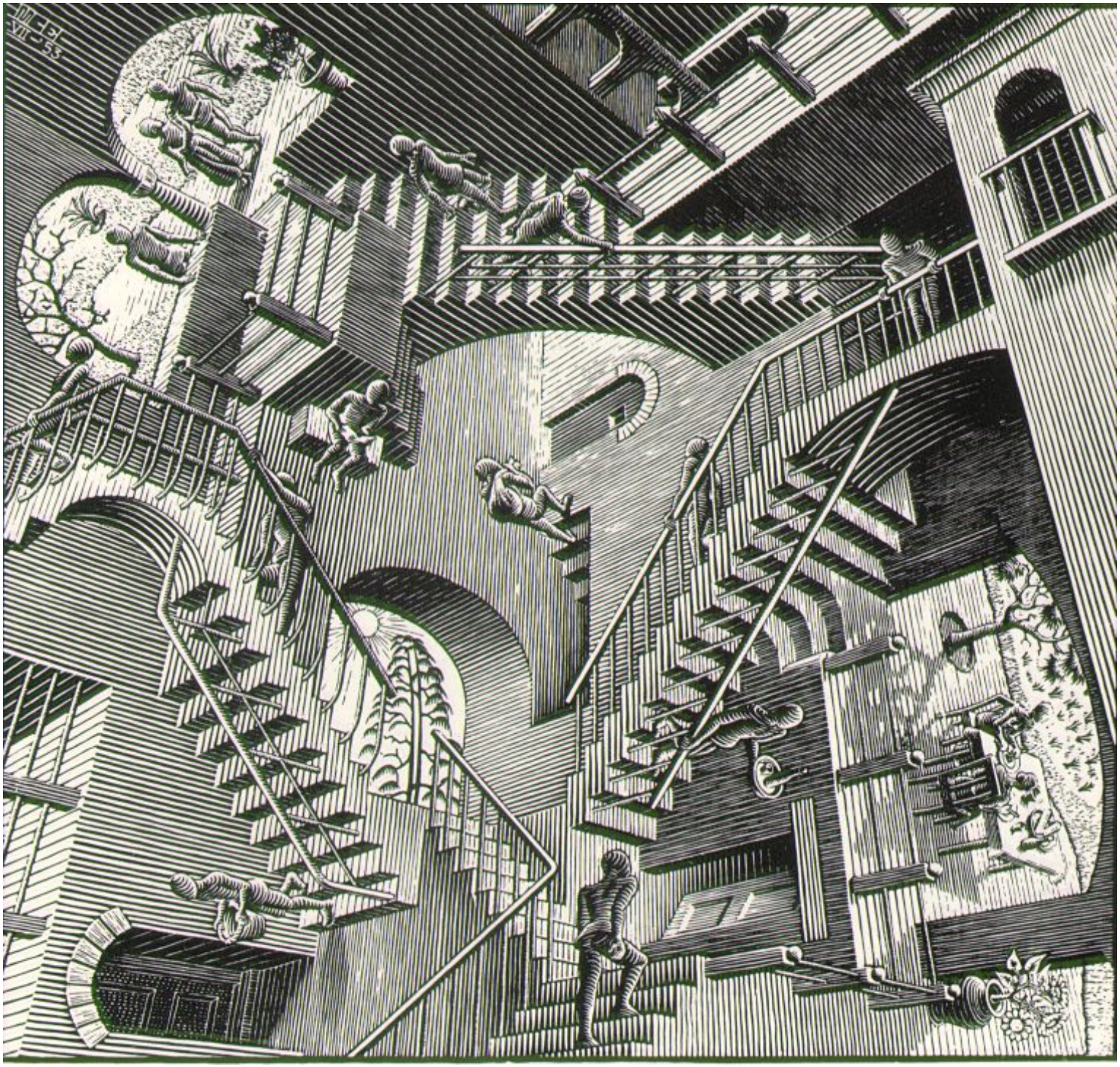


Mannucci, Cresci, et al. 2010

SFR-Z-Mass

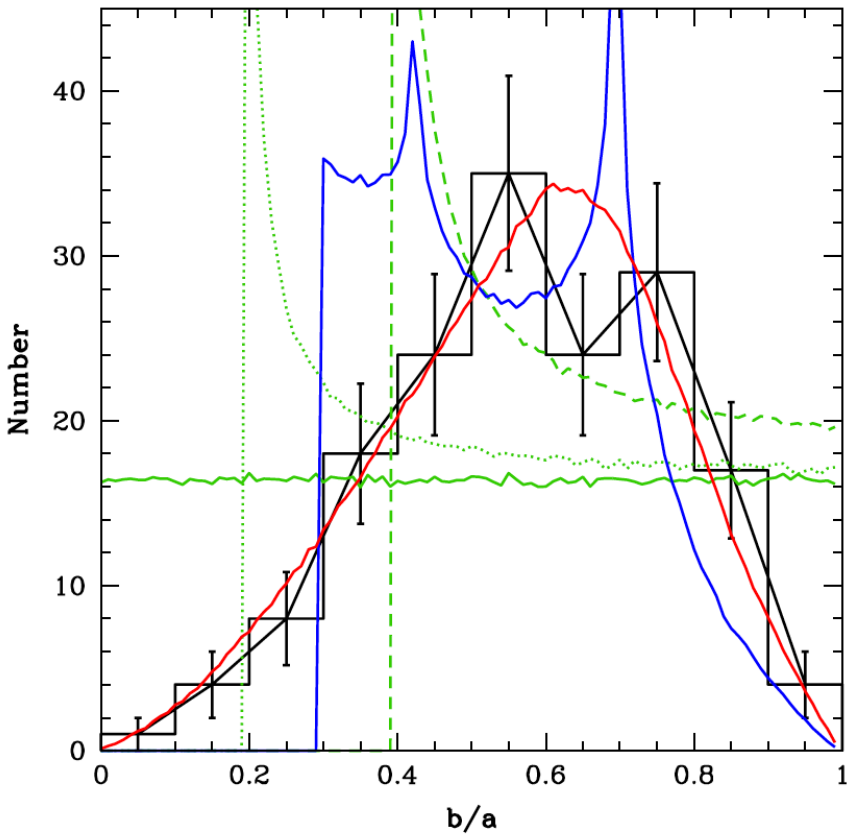


Mannucci, Cresci, et al. 2010



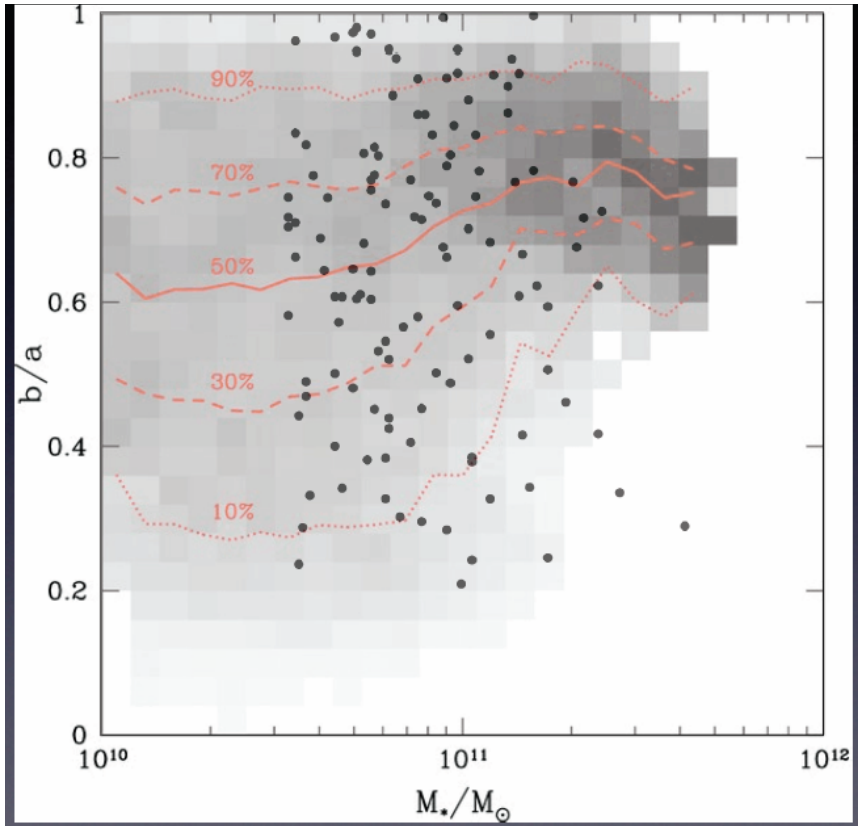
disks are not disks
ellipticals are not elliptical

SF galaxies:



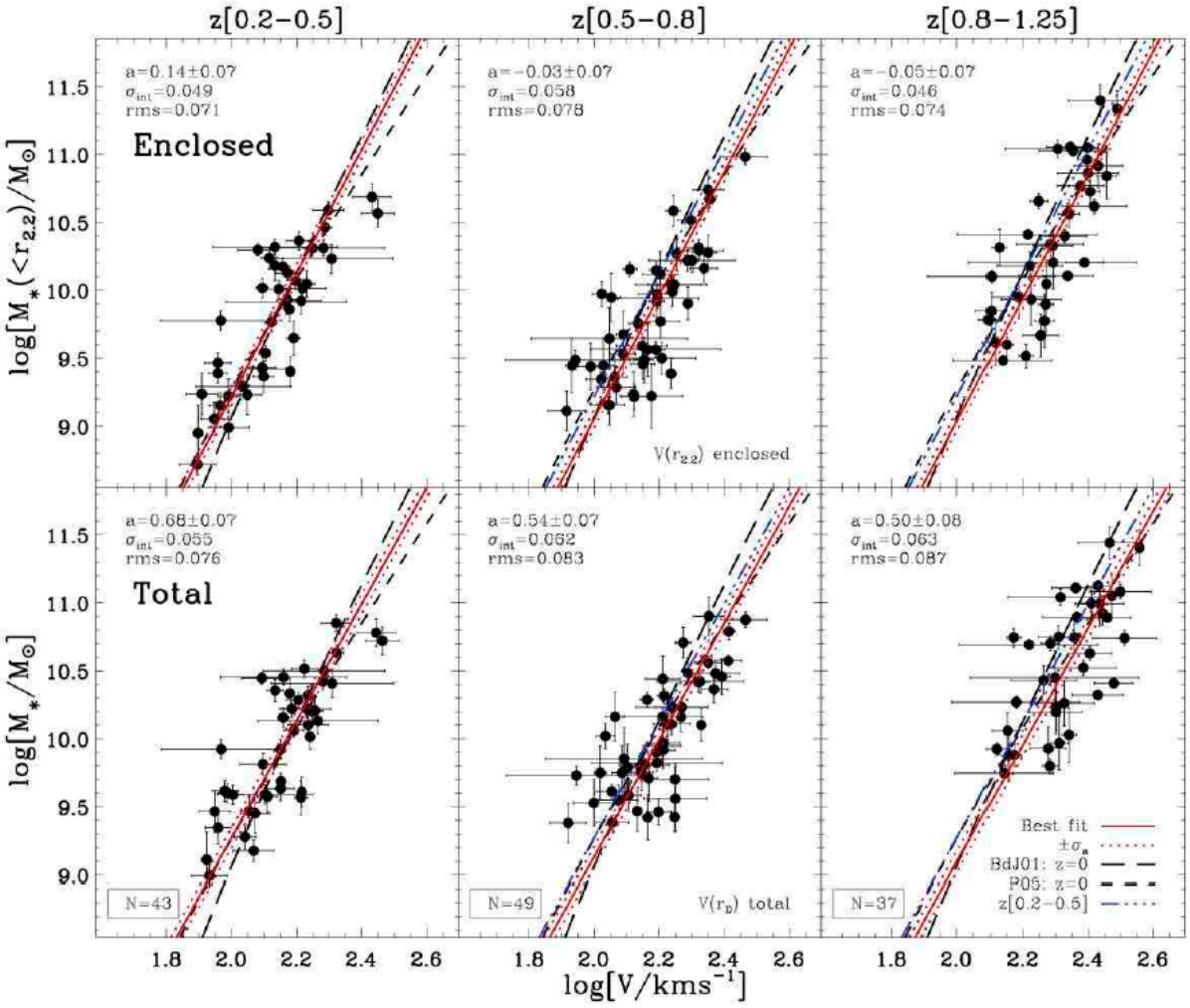
Law et al. 2011

Quiescent galaxies:



van der Wel et al. 2011

Disk galaxy evolution

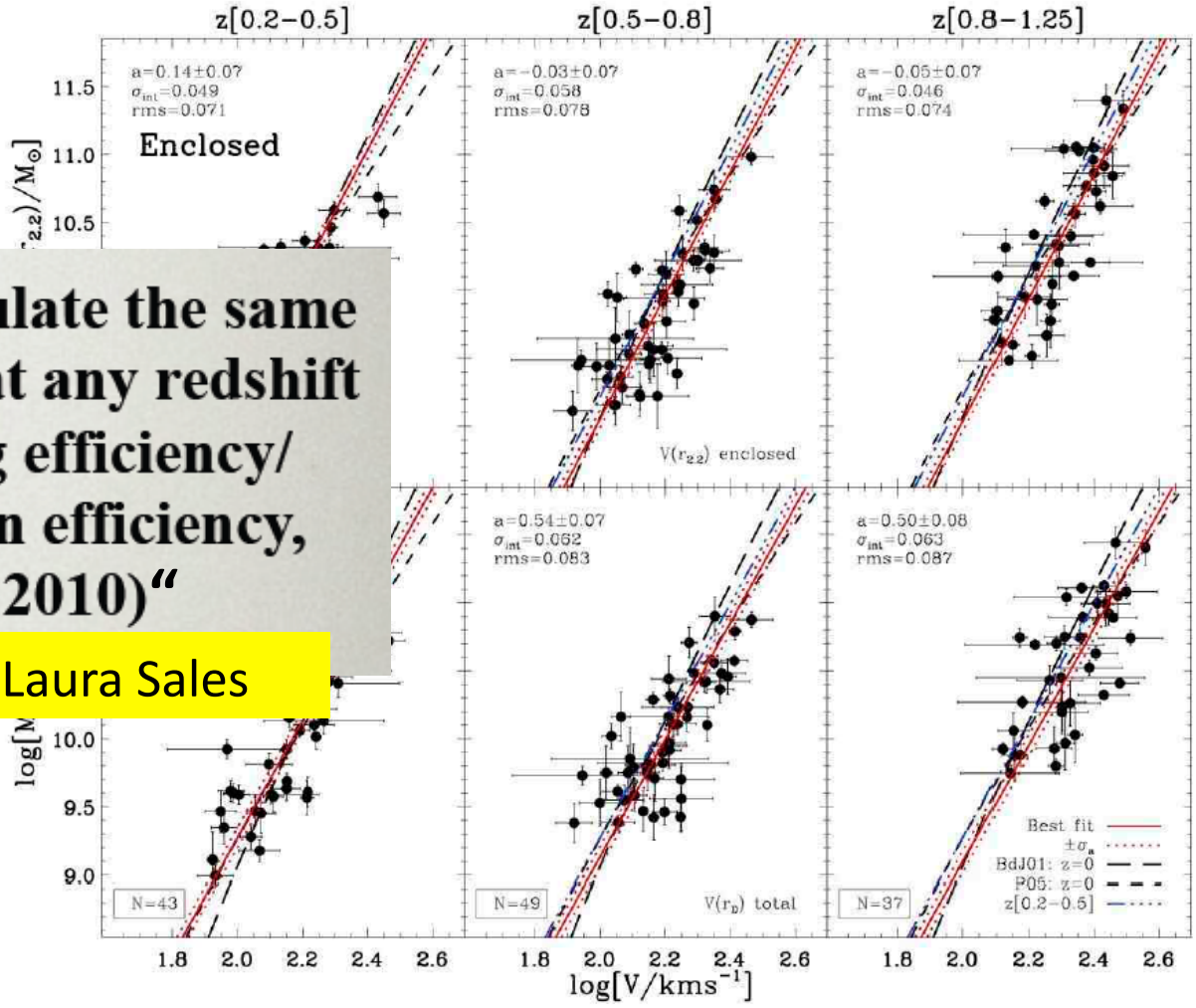


Miller et al. 2011

Disk galaxy evolution

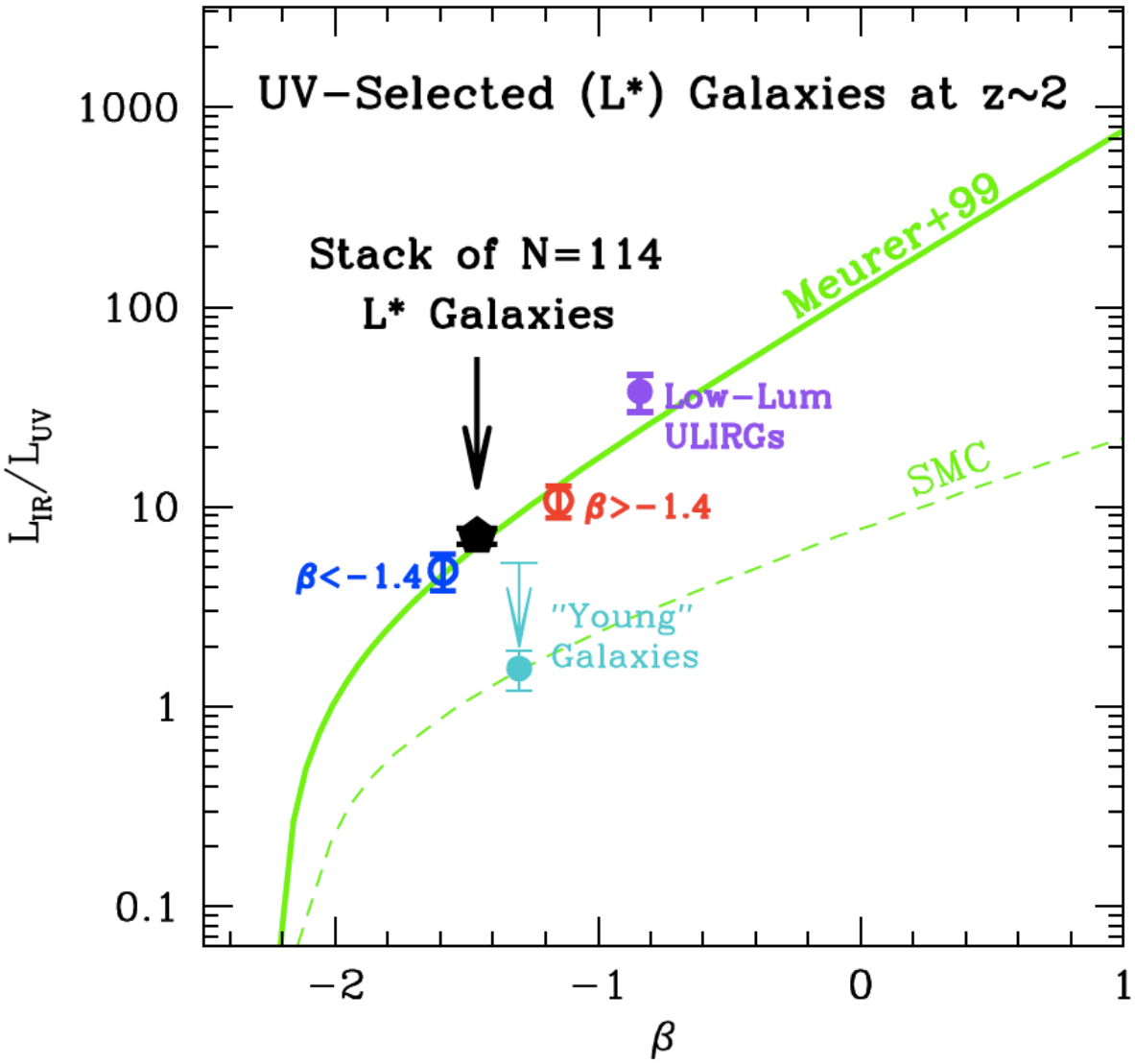
"Disks tend to populate the same virial mass halos at any redshift (peak of cooling efficiency/ galaxy formation efficiency, Guo et al. 2010)"

- Laura Sales



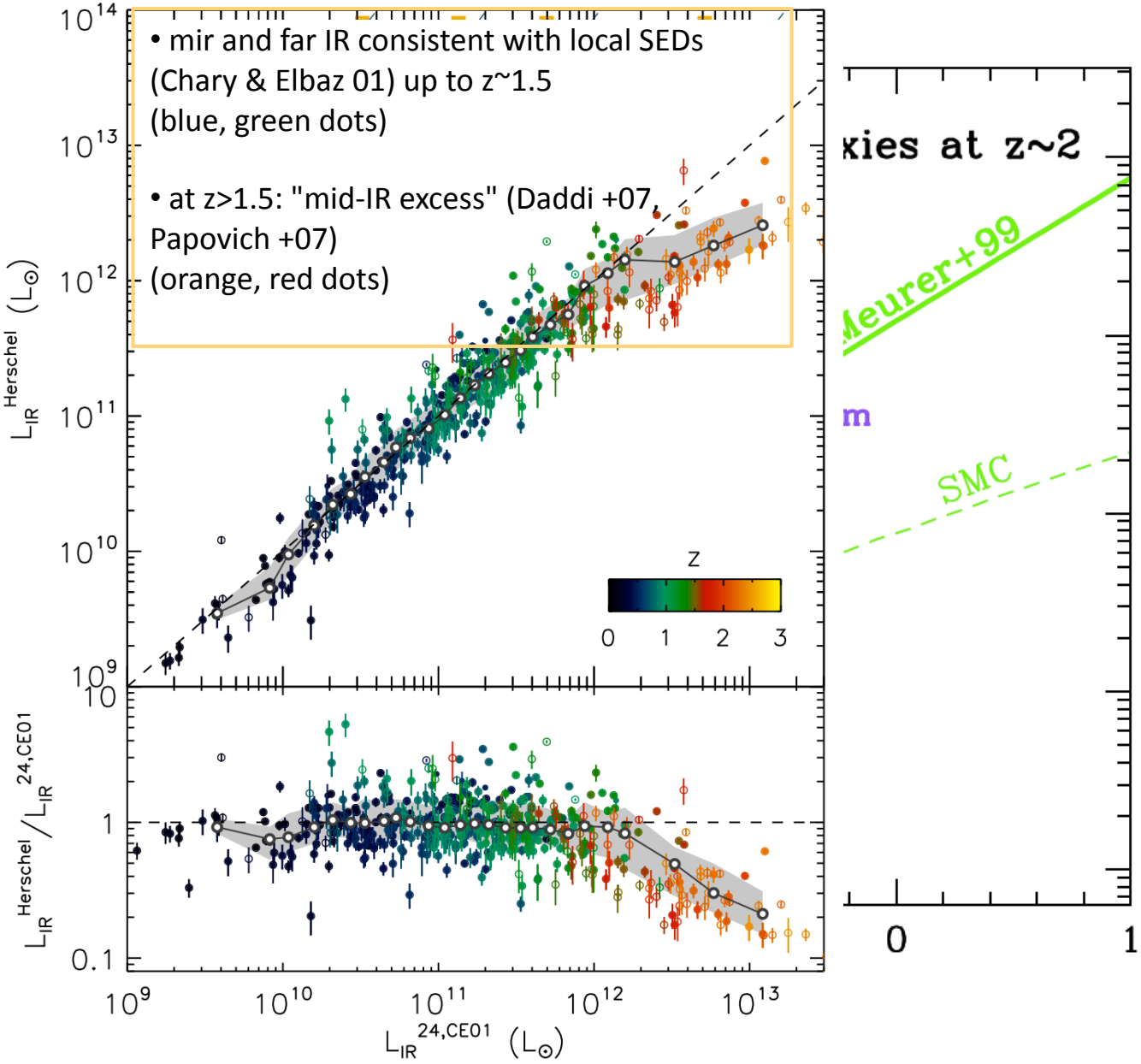
Miller et al. 2011

Dust properties at z=2 and z=0



Reddy et al. 2011

Dust properties at z=2 and z=0

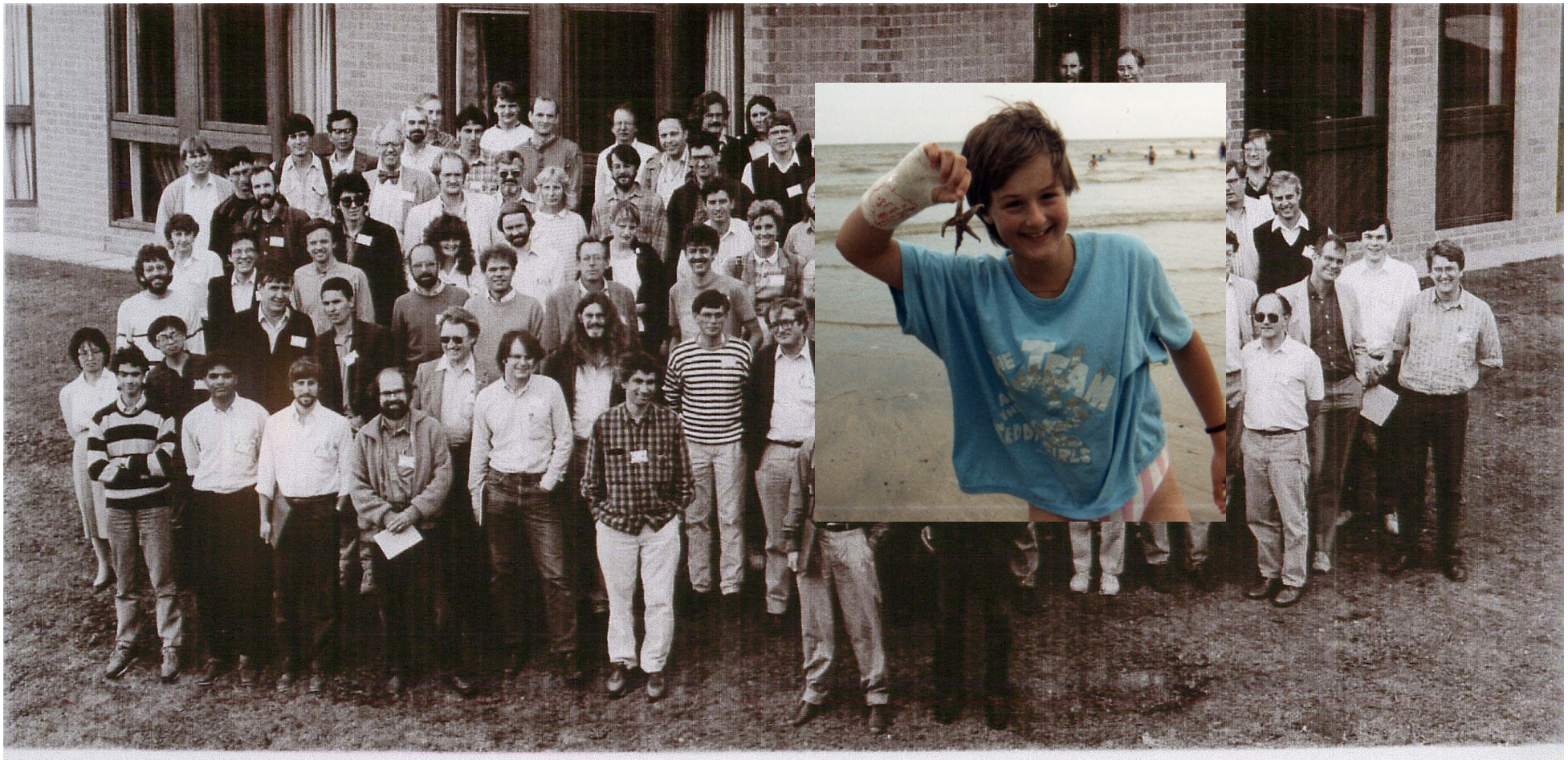


Reddy et al. 2011

Summary of the Summary, part I

- Considering only M_{star}, SFR, M_{halo}, galaxy formation is simple, even boring.

- "10 billion years ago things were the same"
  - Prochaska



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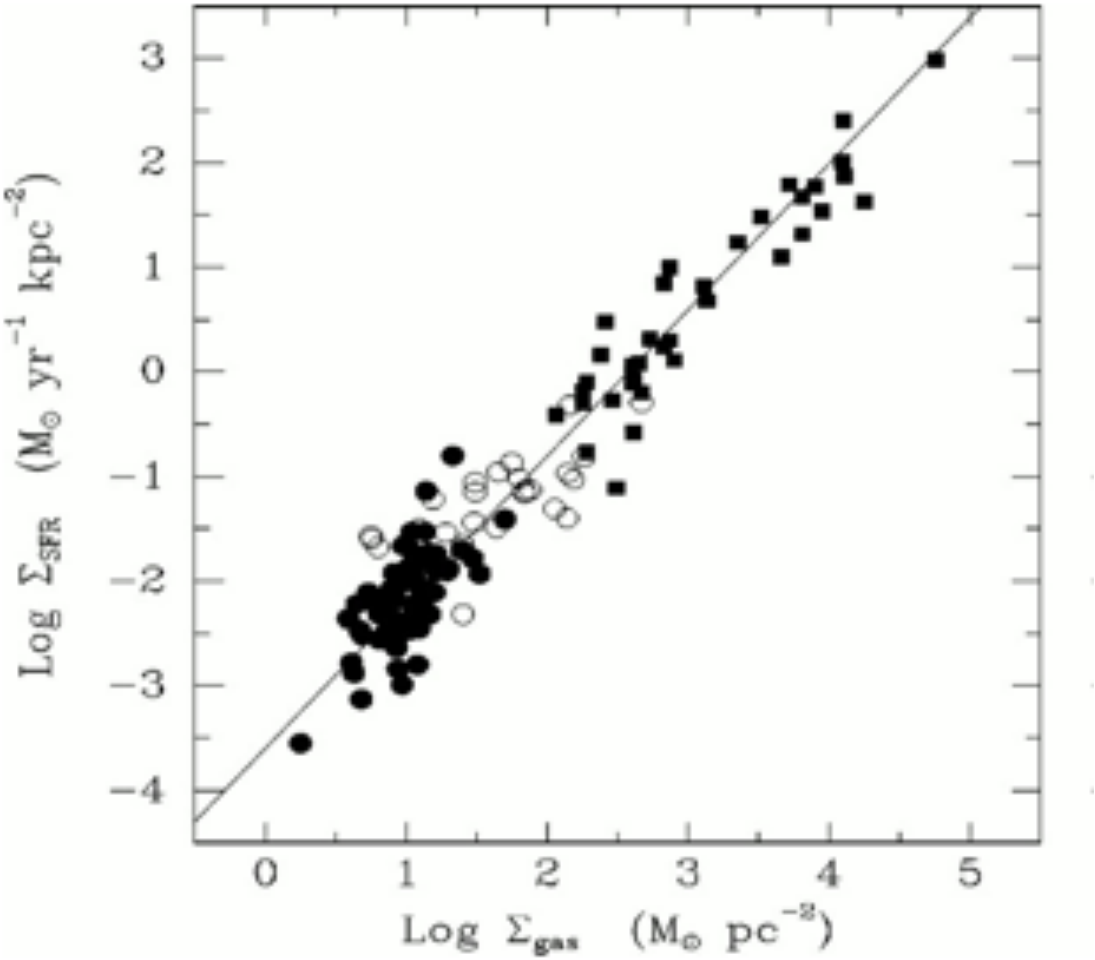
UNIVERSITY OF DURHAM. U.K. JULY 18-22, 1988

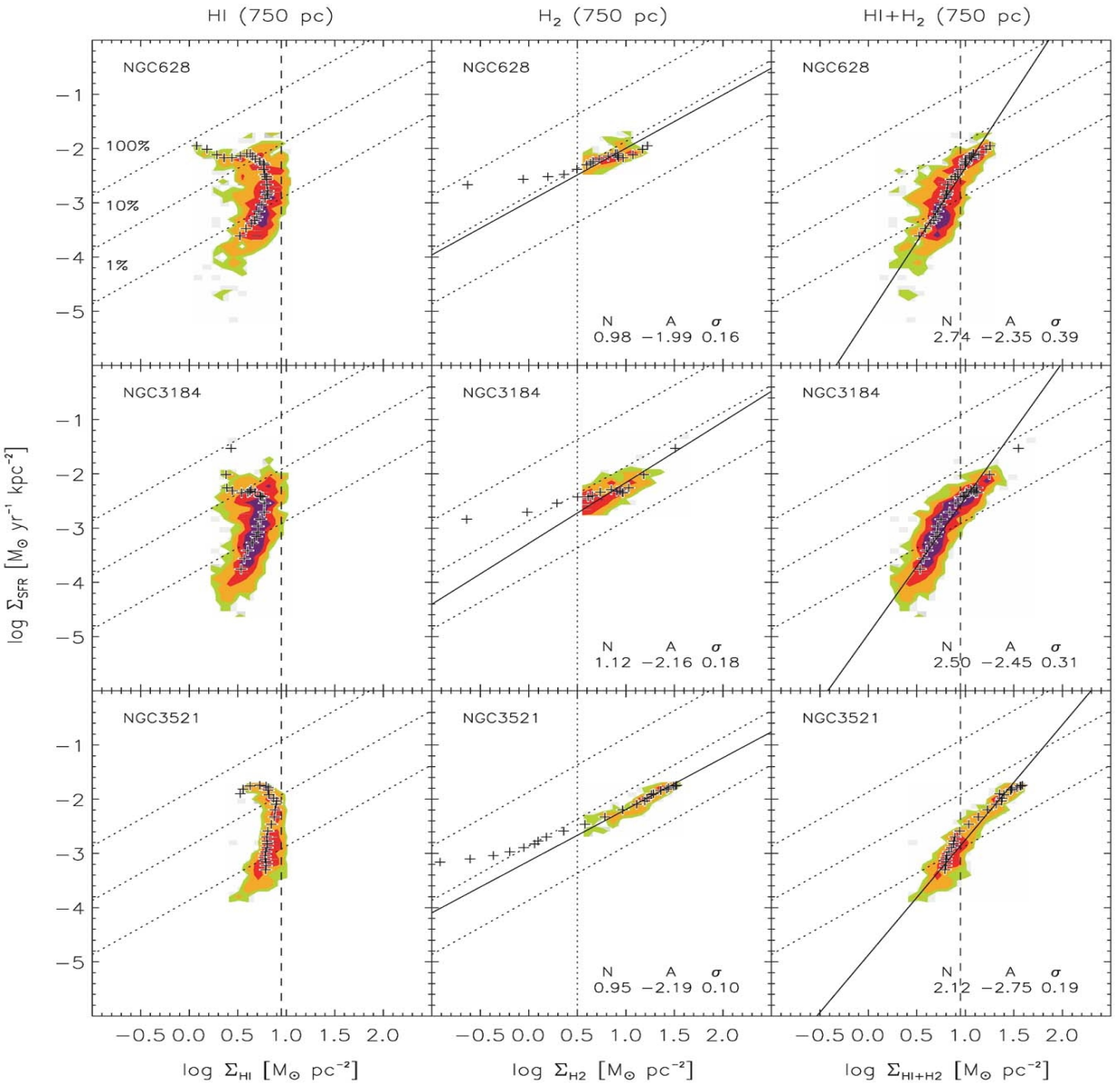
SFR laws in total gas density……



“The field is limited by how we measure star formation laws” -
R. Kennicutt

SFR laws in total gas density……

…. studies on kpc scales and domination of H_2



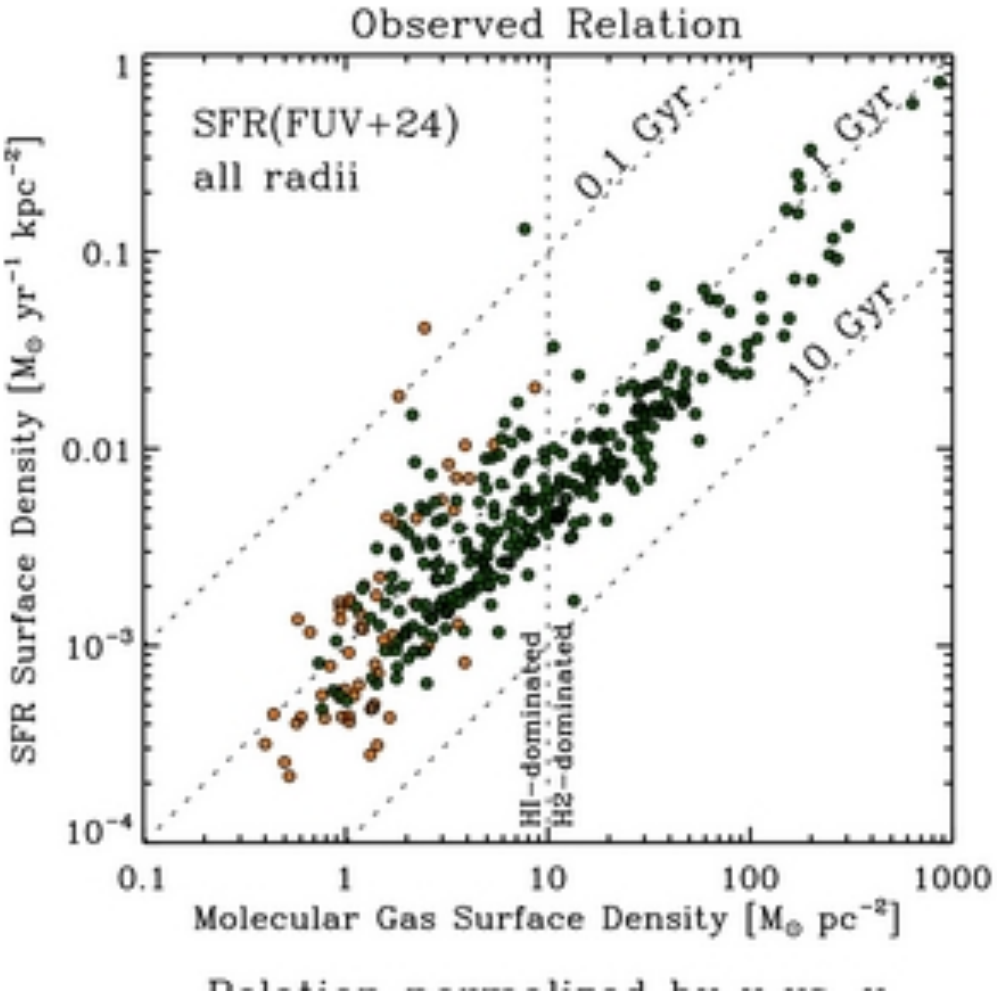
Bigiel et al (2008)

SFR laws in total gas density……

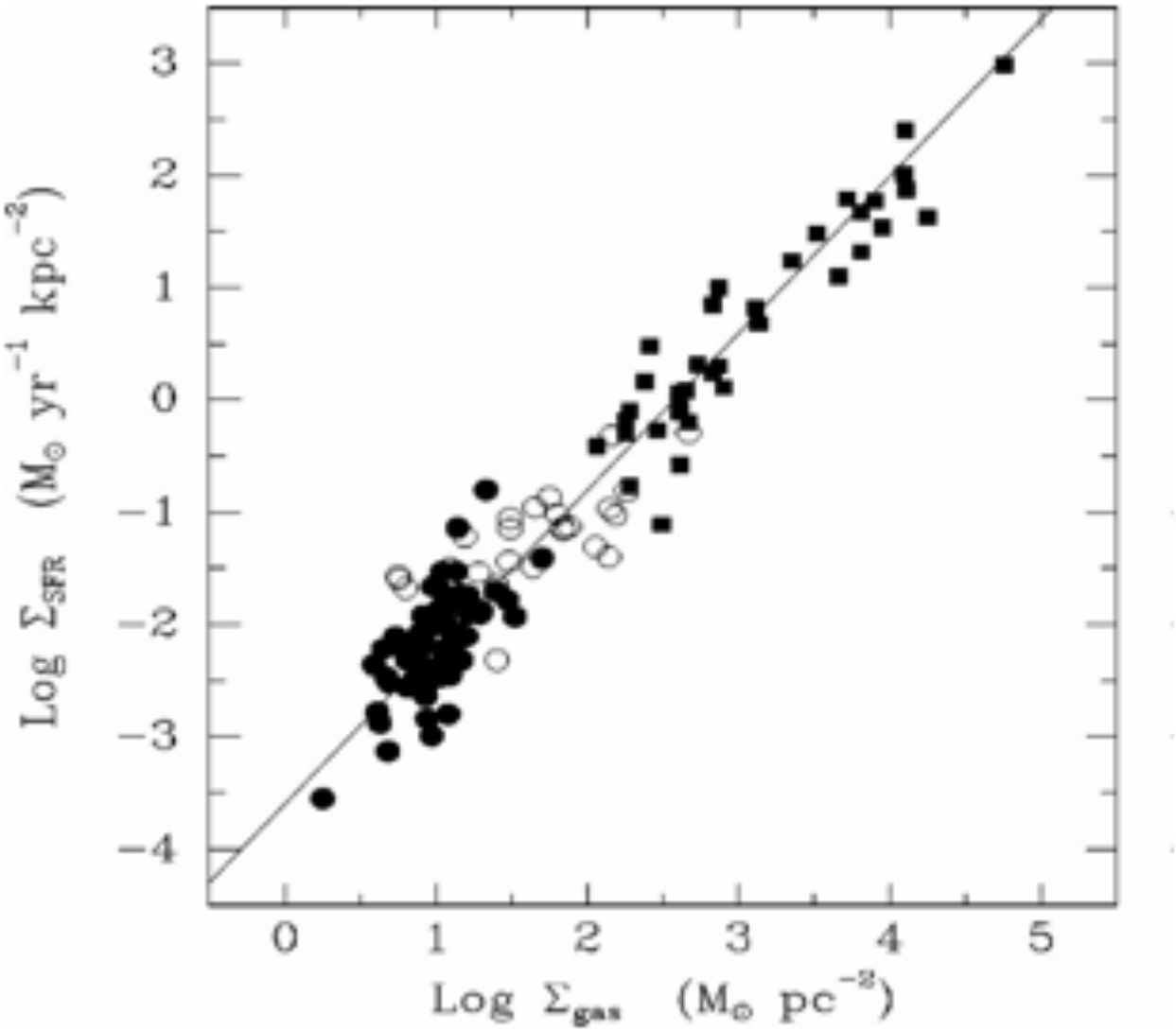
…. studies on kpc scales and domination of H_2….

…. even in atomic regime.

Schruba et al. (2011)



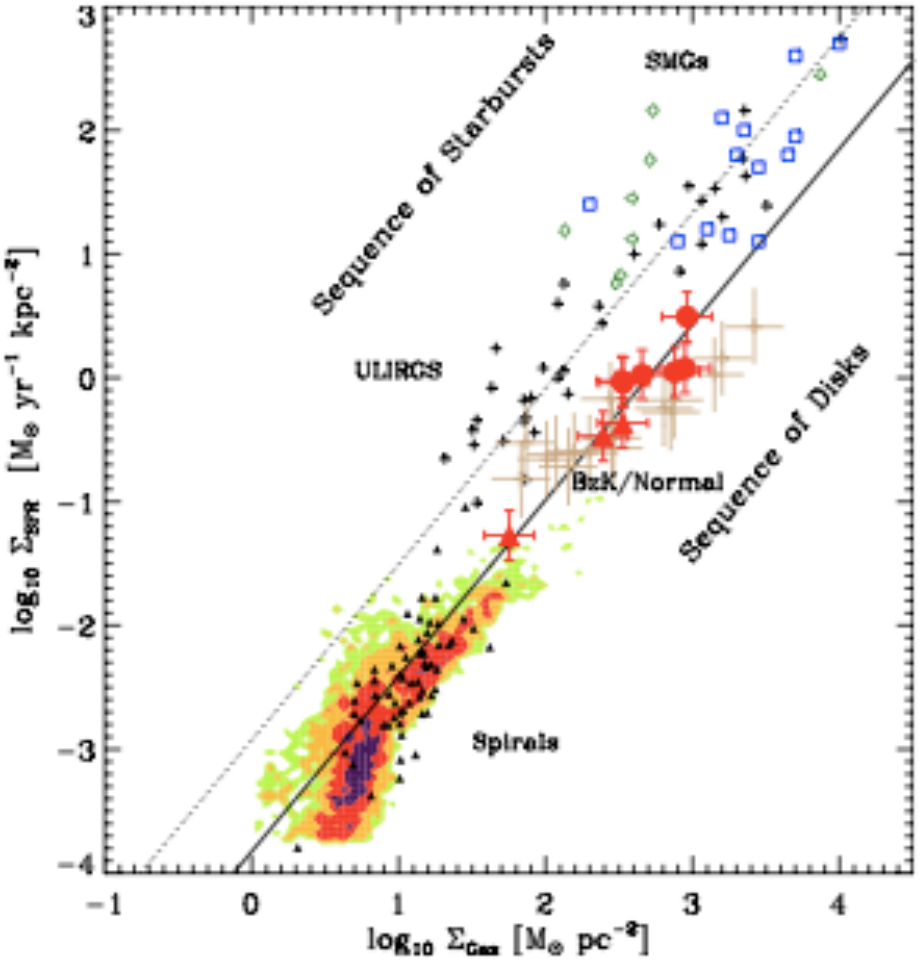
A single star formation law……



A single star formation law……

….. two sequences …..

Daddi et al (2010).



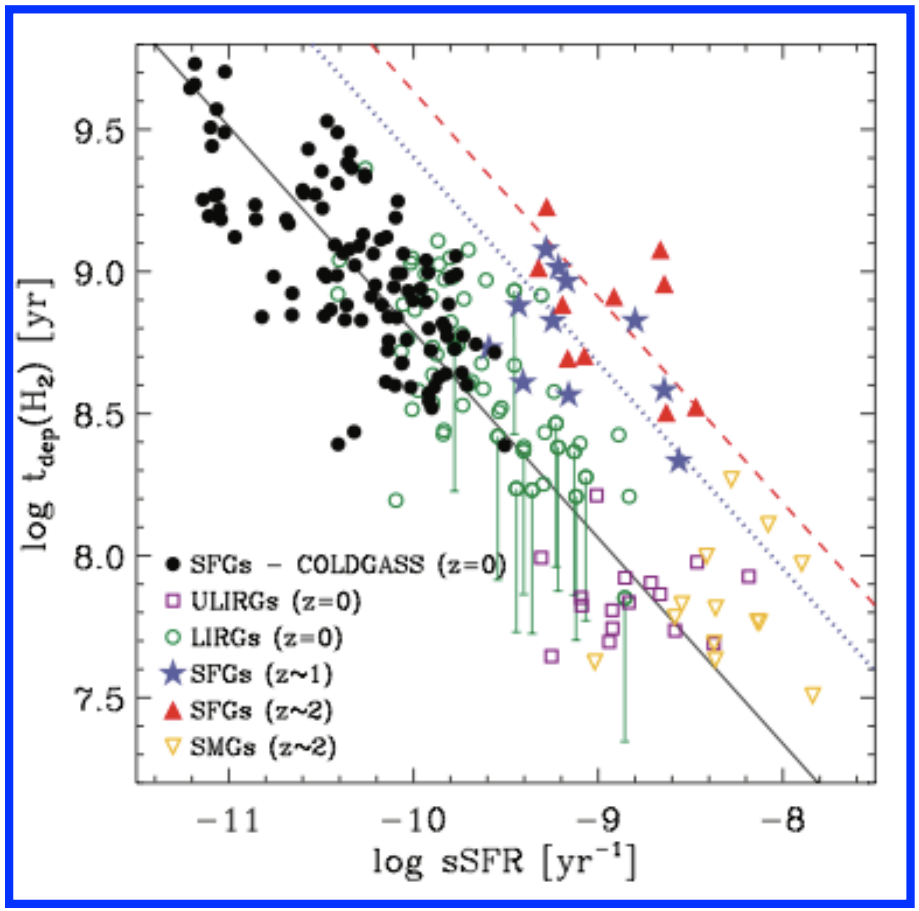
"Main sequence hell and X_{CO} purgatory" - H.-W. Rix

A single star formation law……

….. two sequences …..

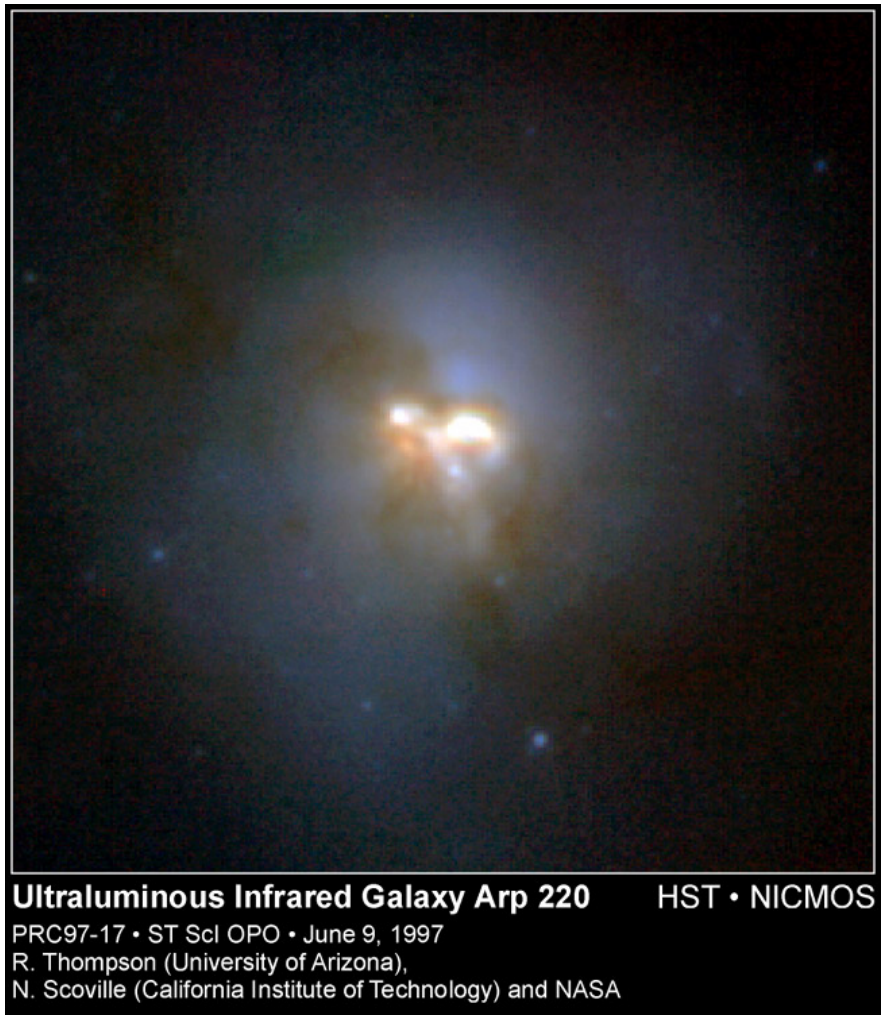
….. smoothly varying depletion times.

Saintonge



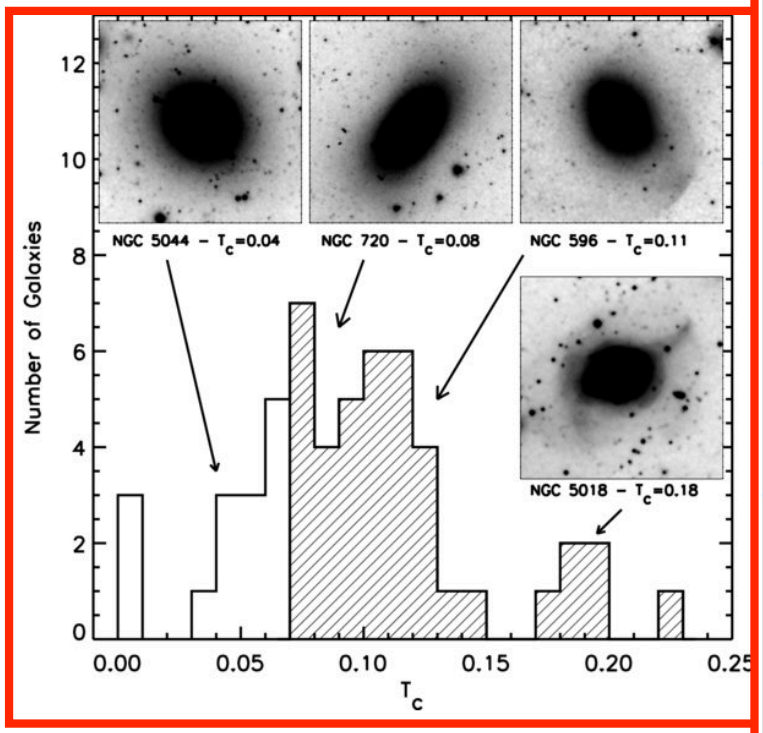
“I never believe bimodalities in astronomy” - M. Colless

Major mergers dominate galaxy evolution…..



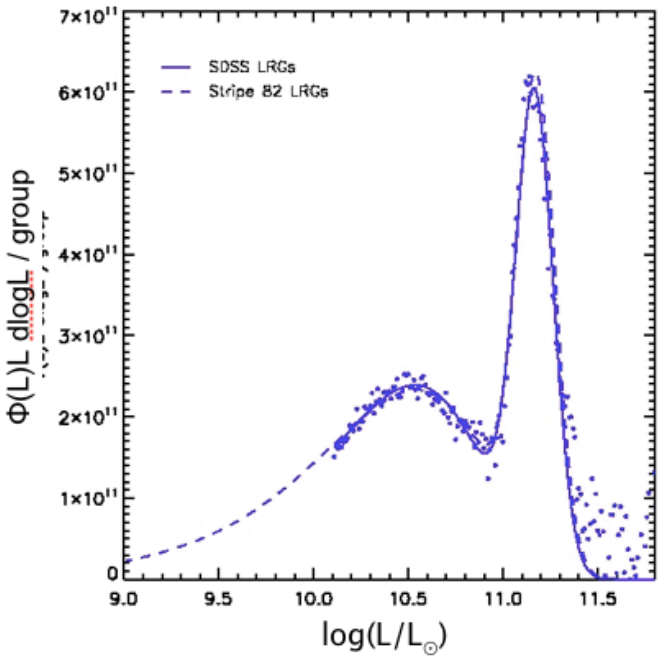
Major mergers dominate galaxy evolution…..

…. role of minor mergers in building up massive galaxies.



The mass growth of LRGs through mergers

- The gap width implies a typical mass ratio of 1:4 between the central galaxy and its most massive satellite
- **Mergers of higher mass ratio within the environment unlikely**



Tal, Newman, Krabbe, Eliche-Moral, Combes, Martinez-Manso

Major mergers dominate galaxy evolution…..

…. role of minor mergers in building up massive galaxies…

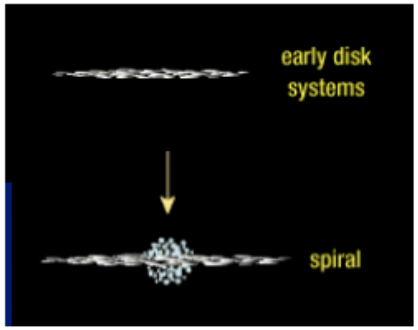
…. Importance of secular processes.

Two modes to assemble and redistribute mass

➔according to epochs and environment

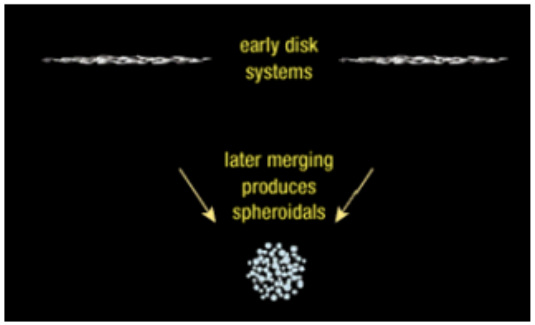
Secular evolution

Internal slow evolution
Through bars, spirals,
+gas accretion

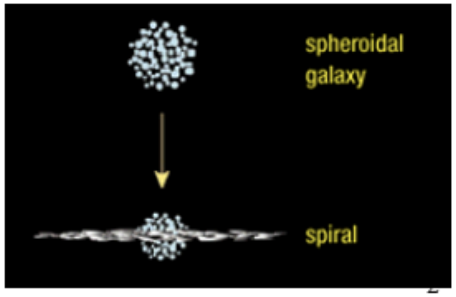


Hierarchical scenario

Spheroids form through major spiral mergers

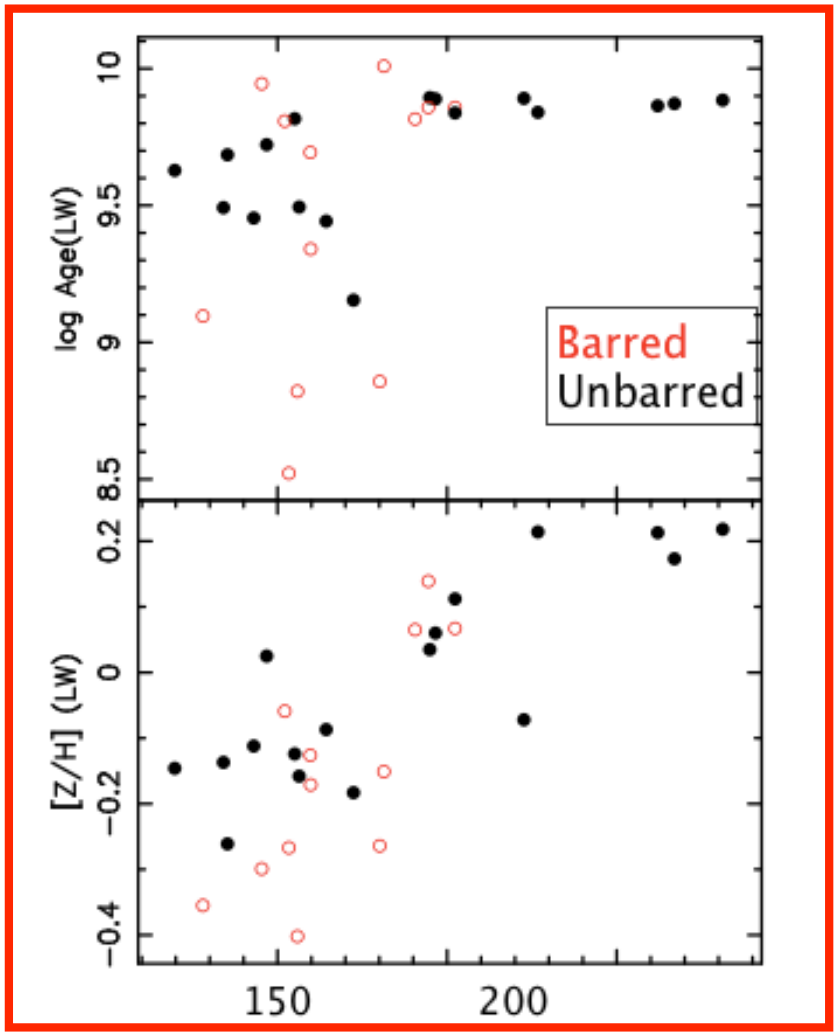


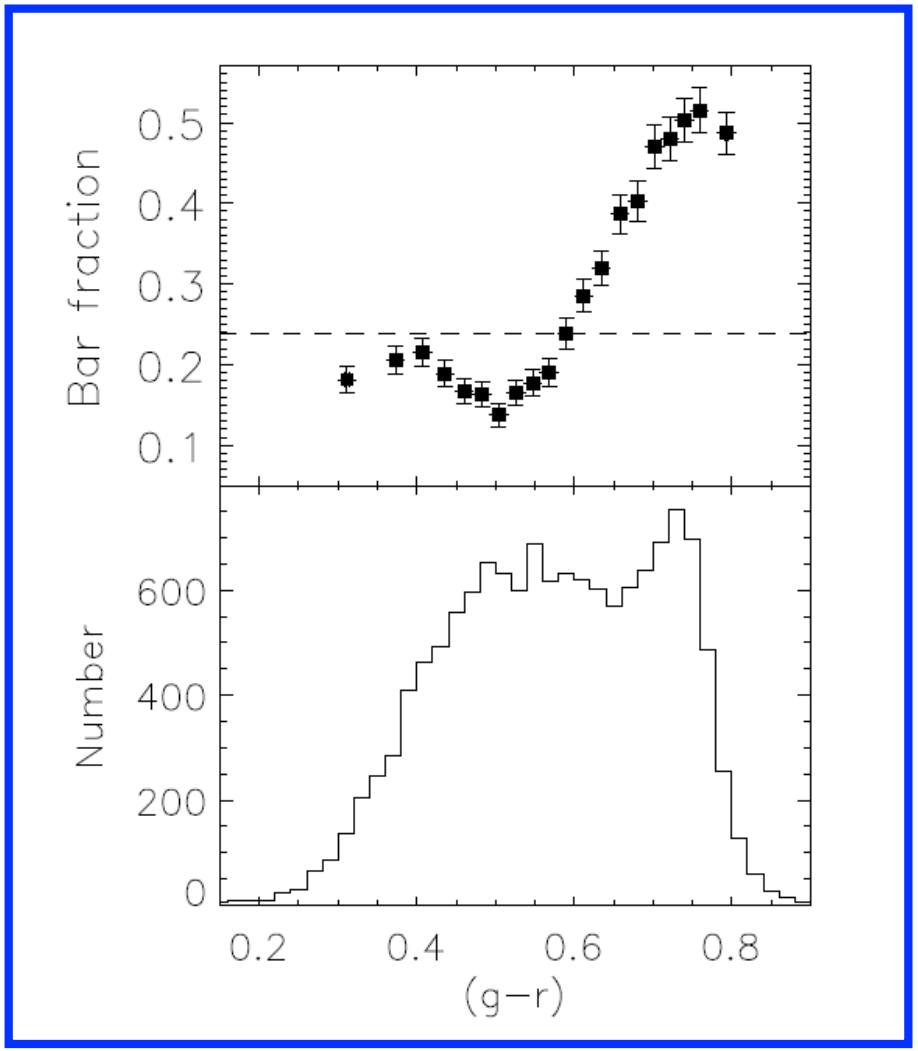
Gas accretion can then reform disks



Combes.

At low redshift, the role of bars for changing stellar populations, star formation rates and metallicities

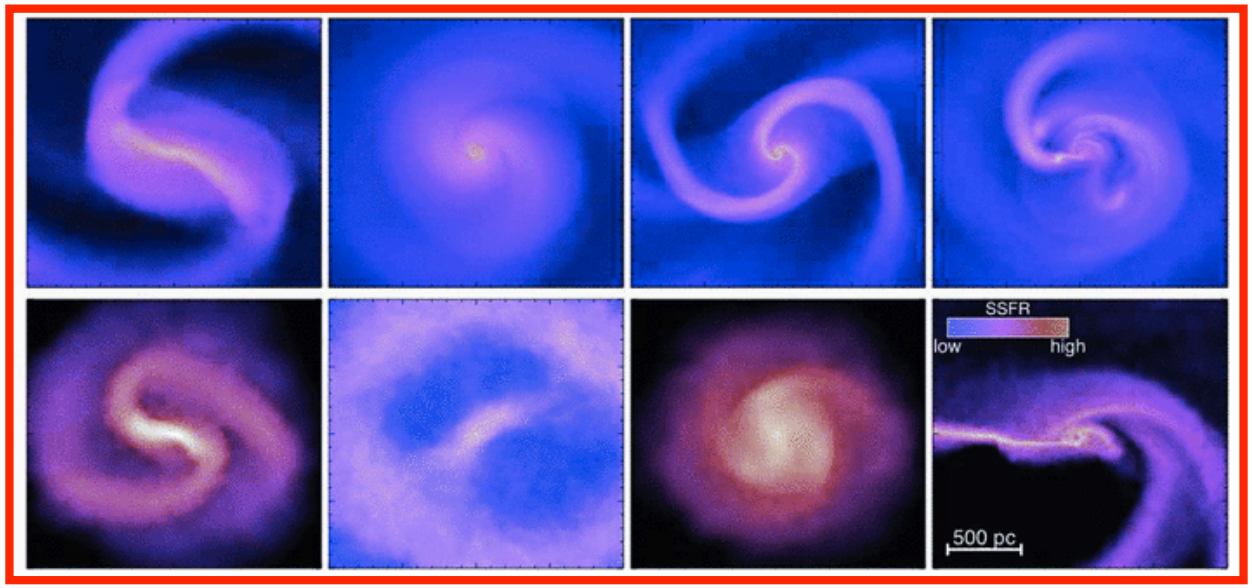


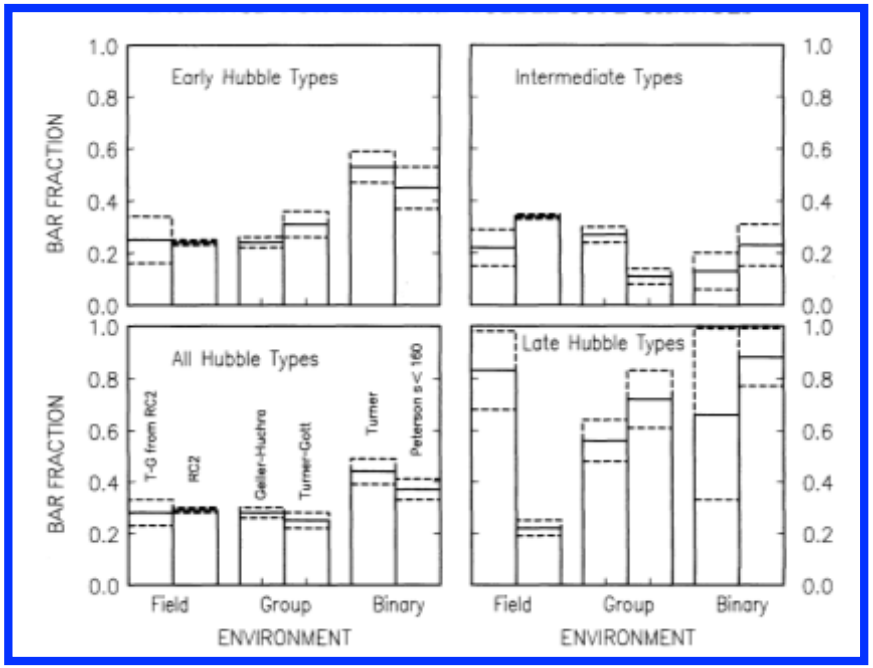


Combes, Sanchez-Blazquez, Nair, Masters, Lablanche, Swartz

Mergers trigger bars…….

Hopkins & Quartert (2010)

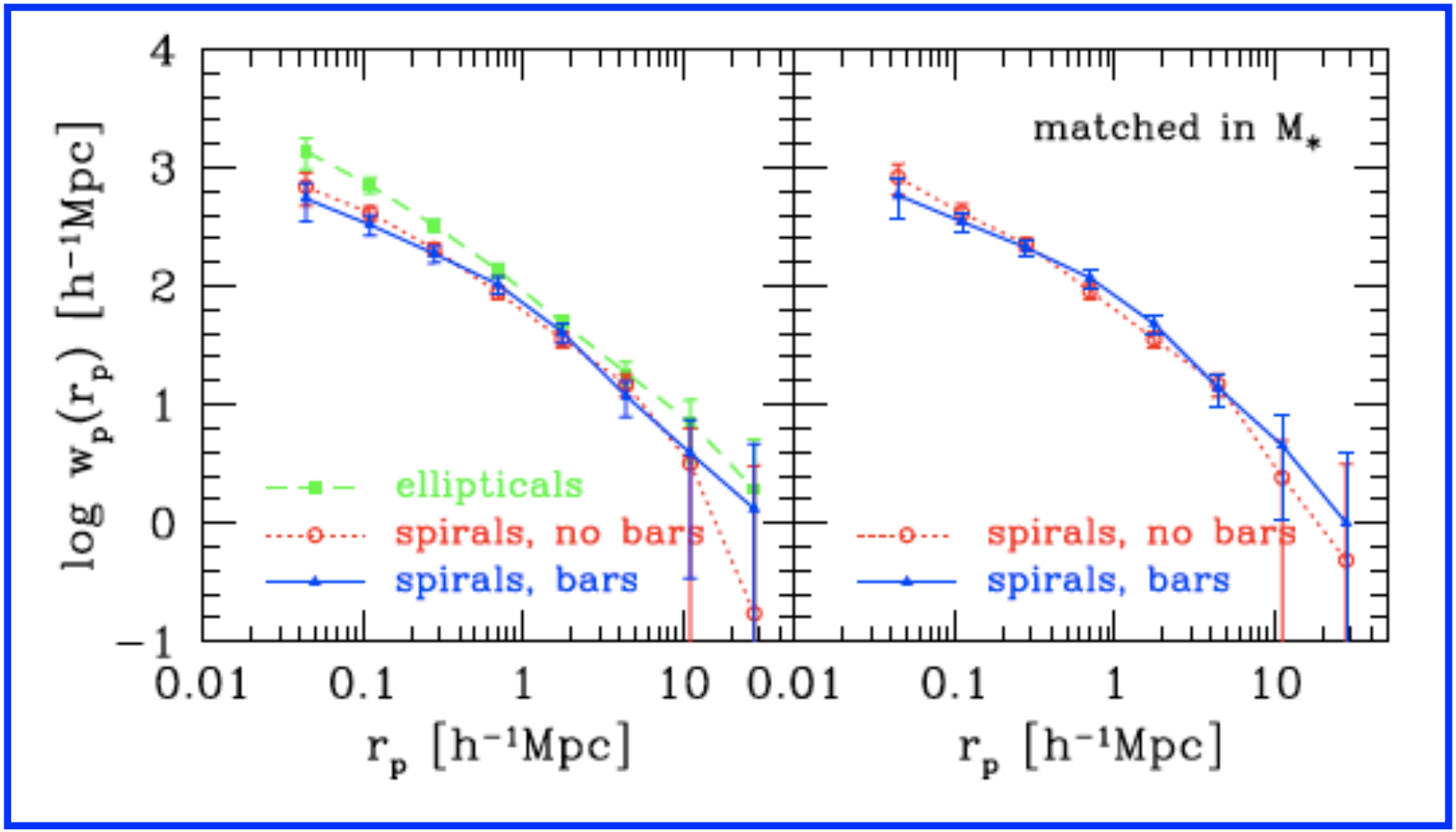




Elmegreen et al. (1990).

Mergers trigger bars……..

….. mergers don’t trigger bars?!!



Li et al. (2009)

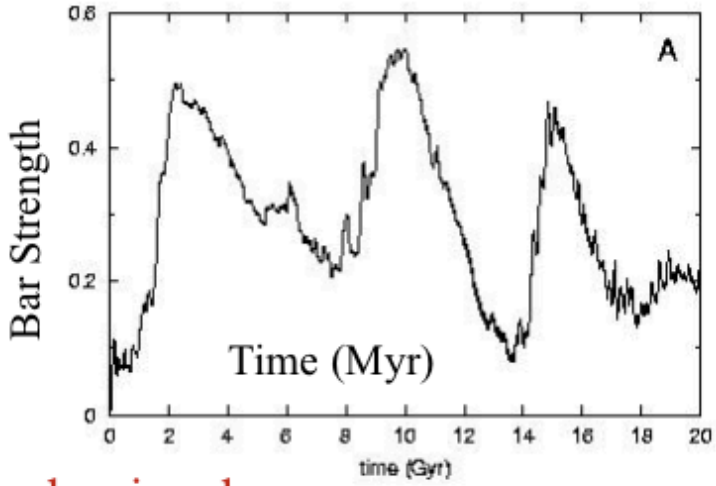
Kauffmann, Eliche-Moral, Nair

Bars formation and destruction

Self-regulated cycle:

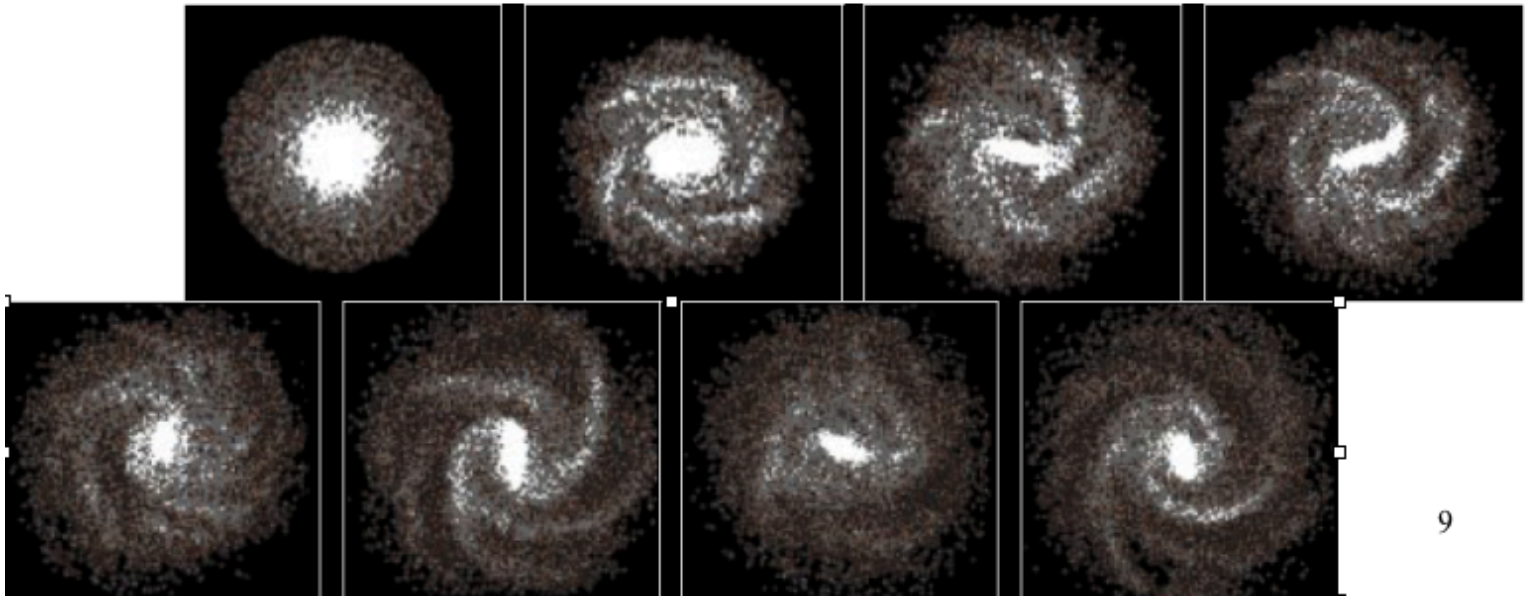
➔Bar produces gas inflow, and

➔Gas inflow destroys the bar



2% of gas infall is enough to transform a bar in a lens

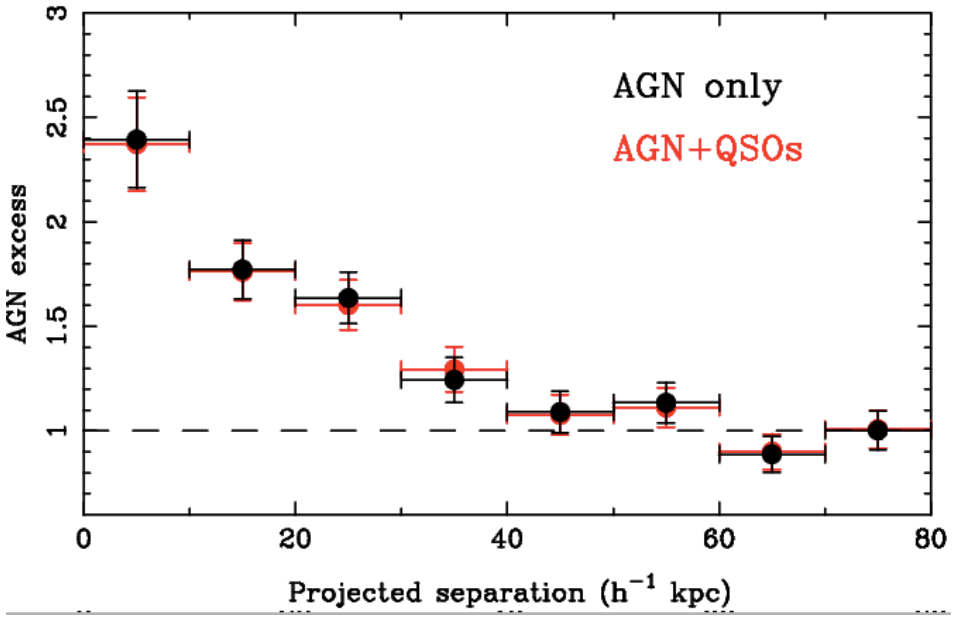
(Friedli 1994, Berentzen et al 1998, Bournaud & Combes 02, 04)

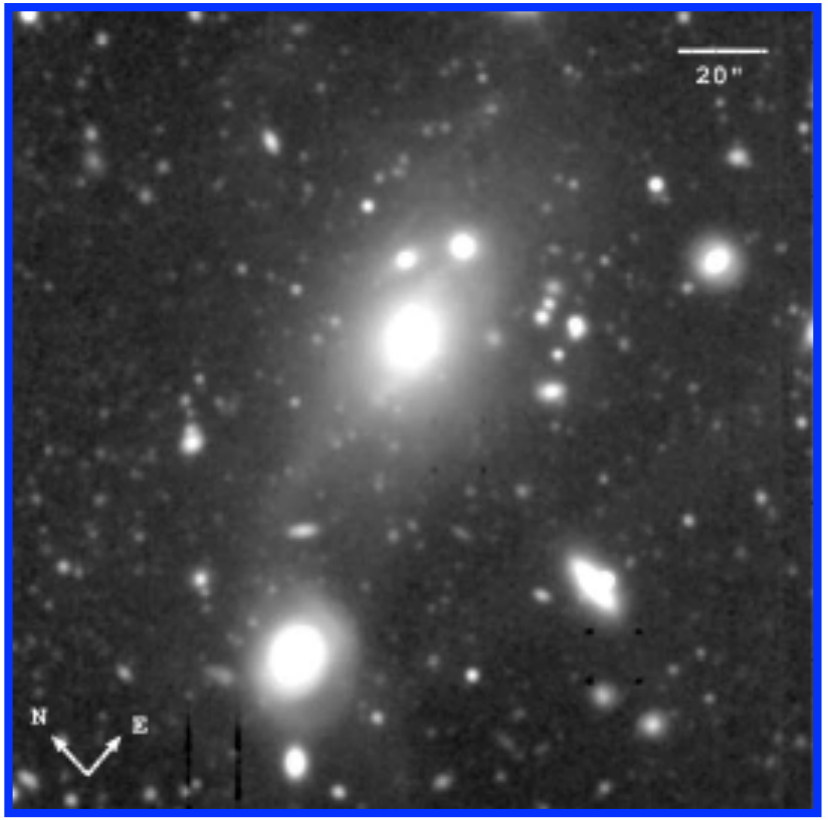


9

Timescales+orbits for bar formation/destruction in mergers?

Mergers trigger AGN….

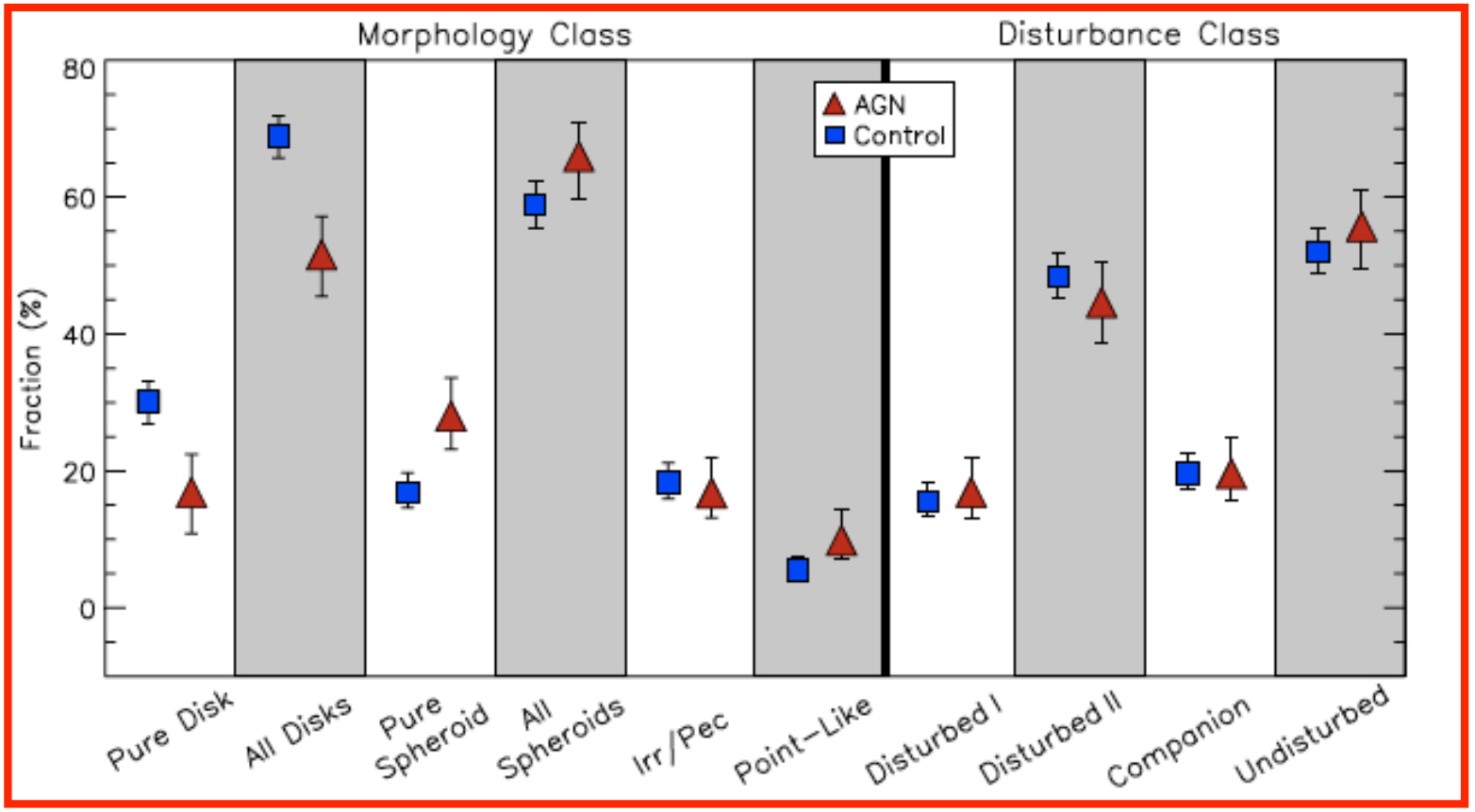




Ramos-Almeida, Bessiere, Lietzen, U, Karouzos, Trouille.

Mergers trigger AGN….

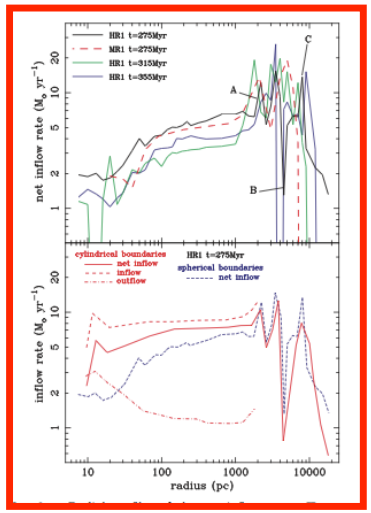
….. But they are not the only trigger.



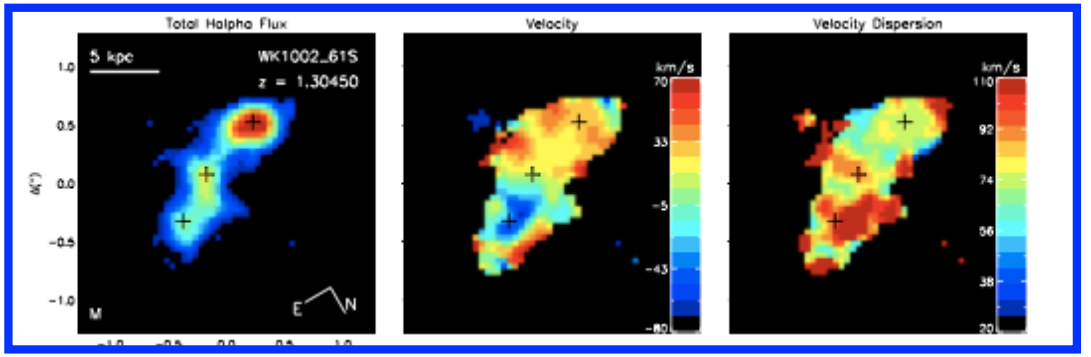
Kocevski, Alexander, Heckman, Novak, Schawinski, Mullaney

Genzel paraphrased: “It doesn’t matter how you get the gas to the central few kpc, but then you have to get it to the nucleus”.

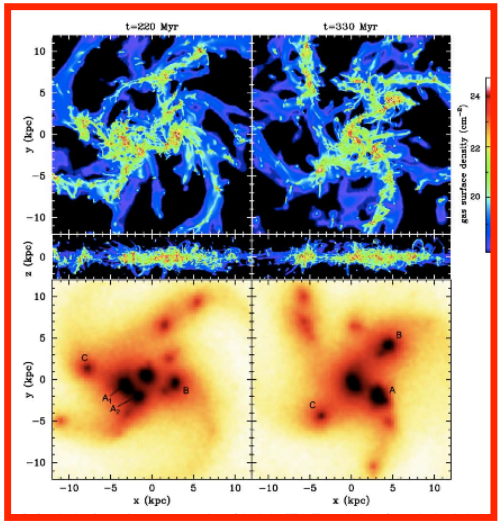
Gas rich disks highly unstable, could trigger AGN, but not clear how common this is observationally.

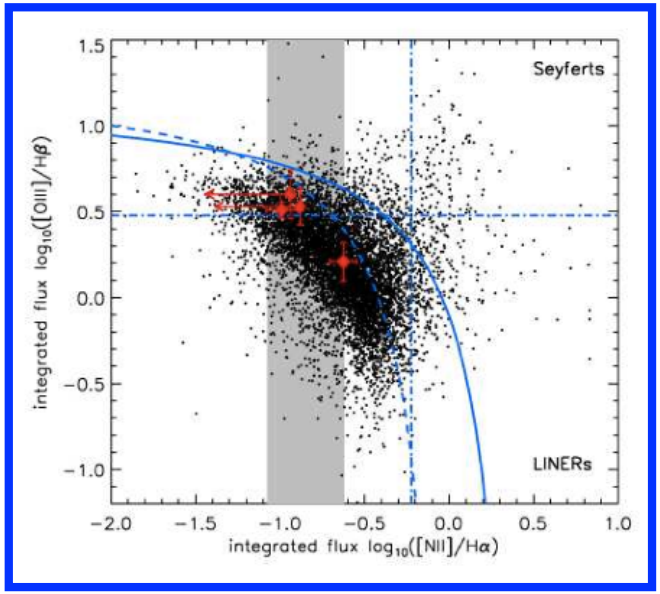


Bournaud et al. (2011)

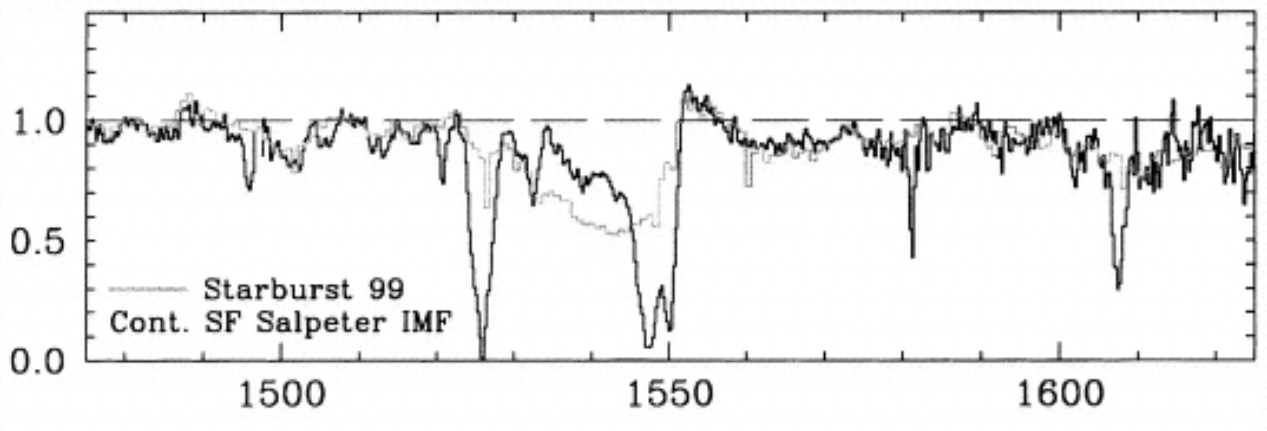


Wisnioski et al. (2011)

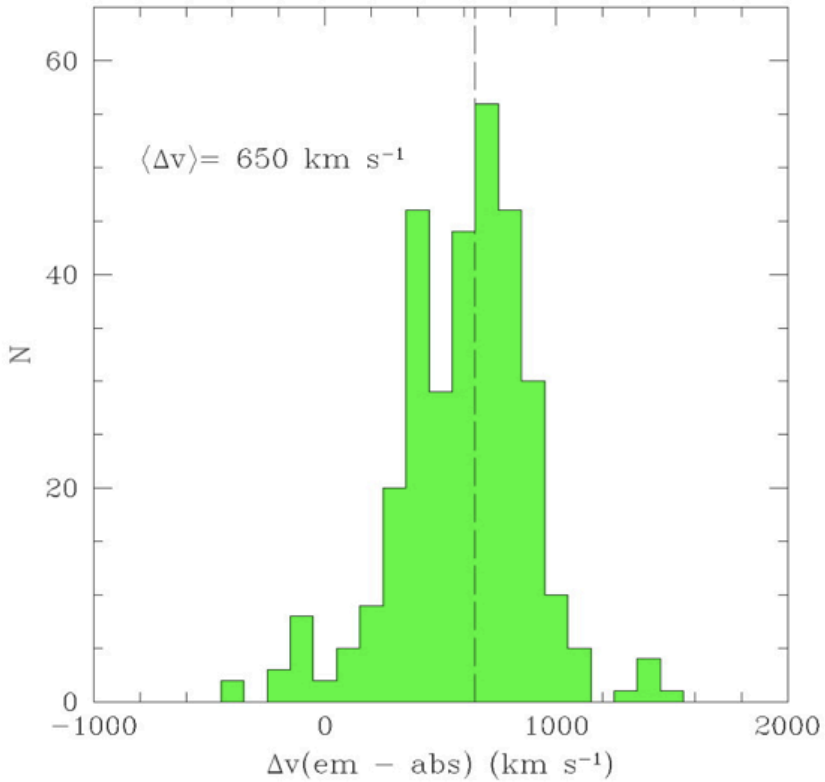




Some high z galaxies have powerful winds….



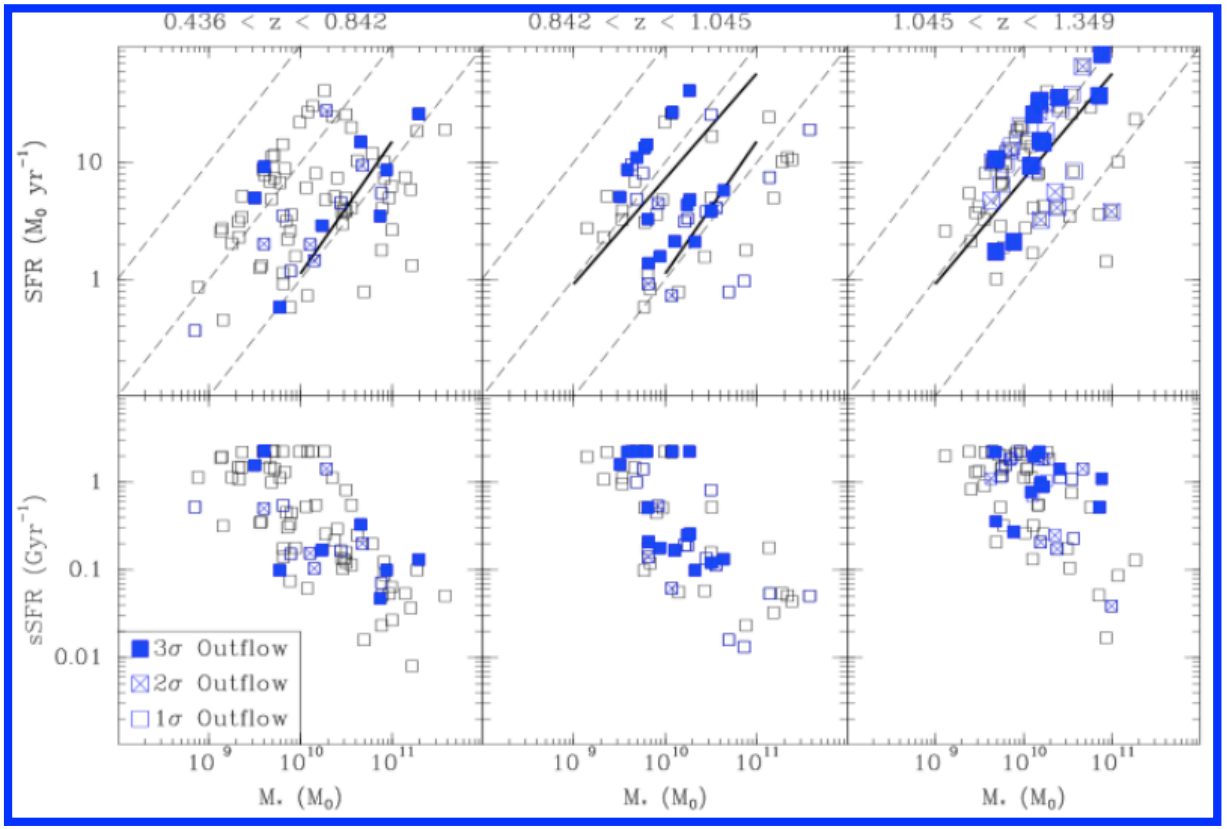
Pettini et al. (2000)



Shapley et al. (2003)

Some high z galaxies have powerful winds….

… winds are ubiquitous in moderate/high z galaxies.



Kornei, Harrison, Lilly, Martin, Steidel, Weiner, Haehnelt,
Dave, Rudie, Oppenheimer, Lehner, Thiart, Harrison, Law, Newman

“Almost everything at high z has an outflow” - C. Steidel

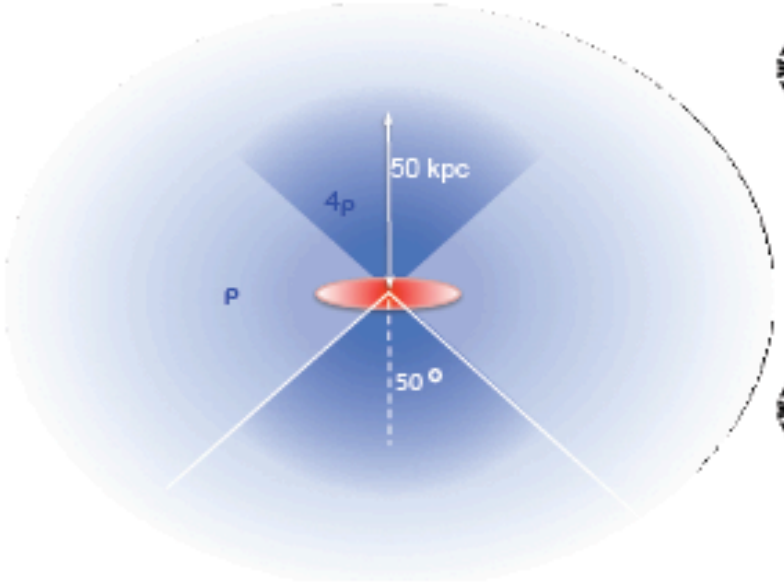
Interpretation of MgII: winds versus disks/halos

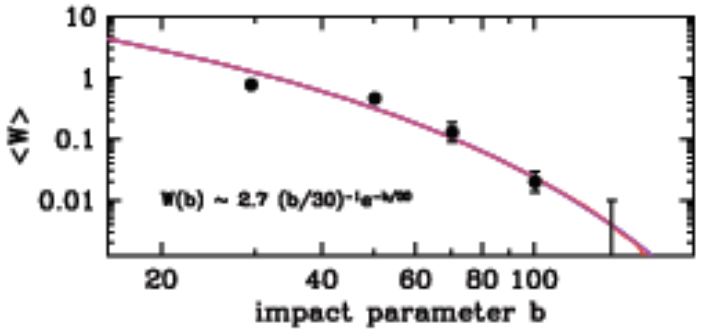
Ubiquitous winds: mass loss ~ SFR

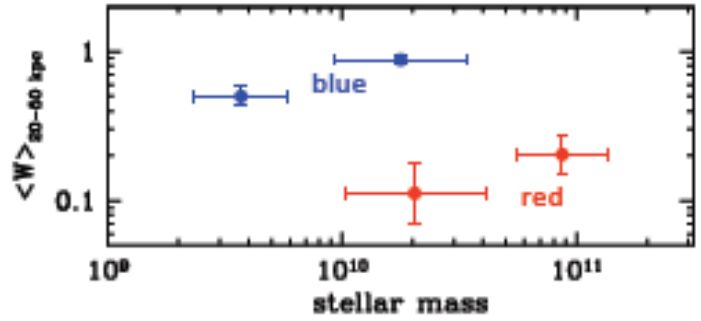
- Cause of extended MgII absorption haloes at b < 50 kpc ?

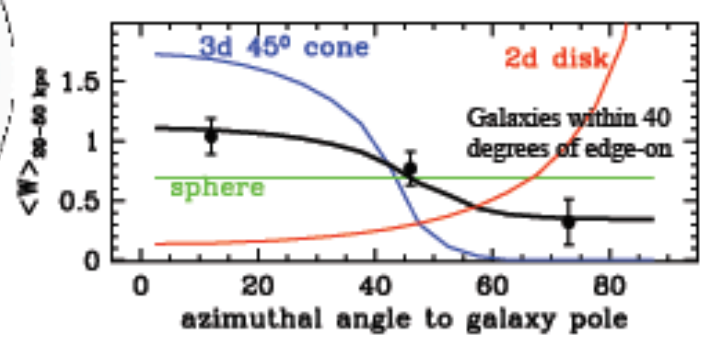
  Bordoloi et al (2011)
  (but see also Kacprzak et al 2010)

Stacked spectra of ~ 5200 zCOSMOS
z > 1.2 galaxies lying behind 4000
0.5 < z < 0.9 galaxies with b < 200 kpc



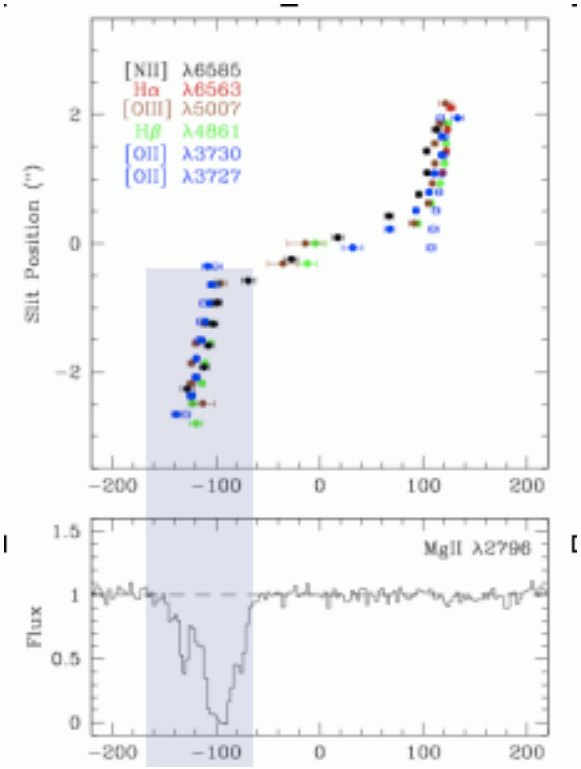


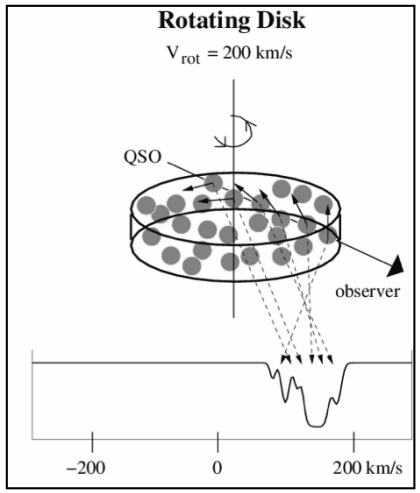




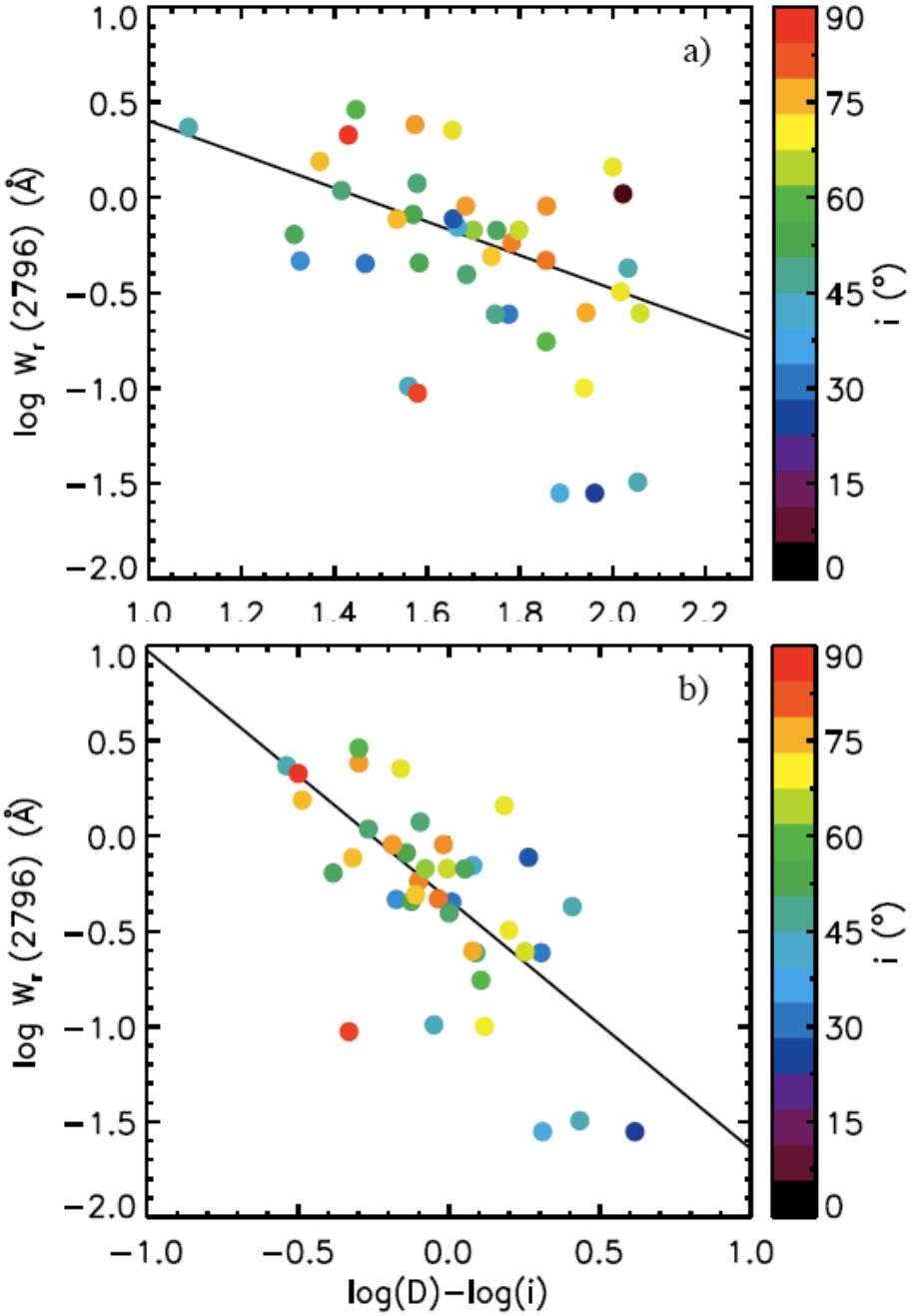
Lilly

Not all MgII is in winds. QSO absorption lines can probe disk.

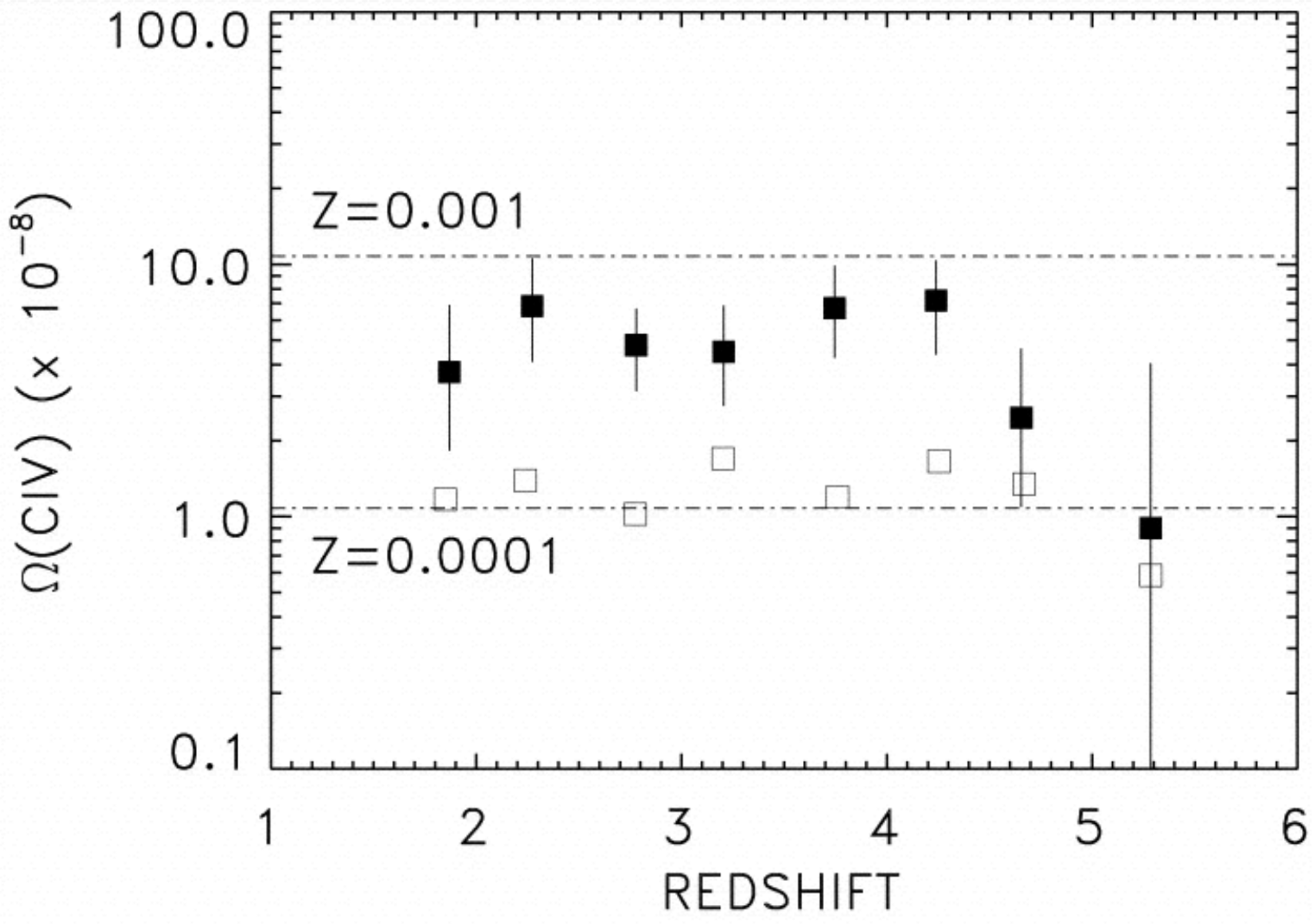




Kacprzak



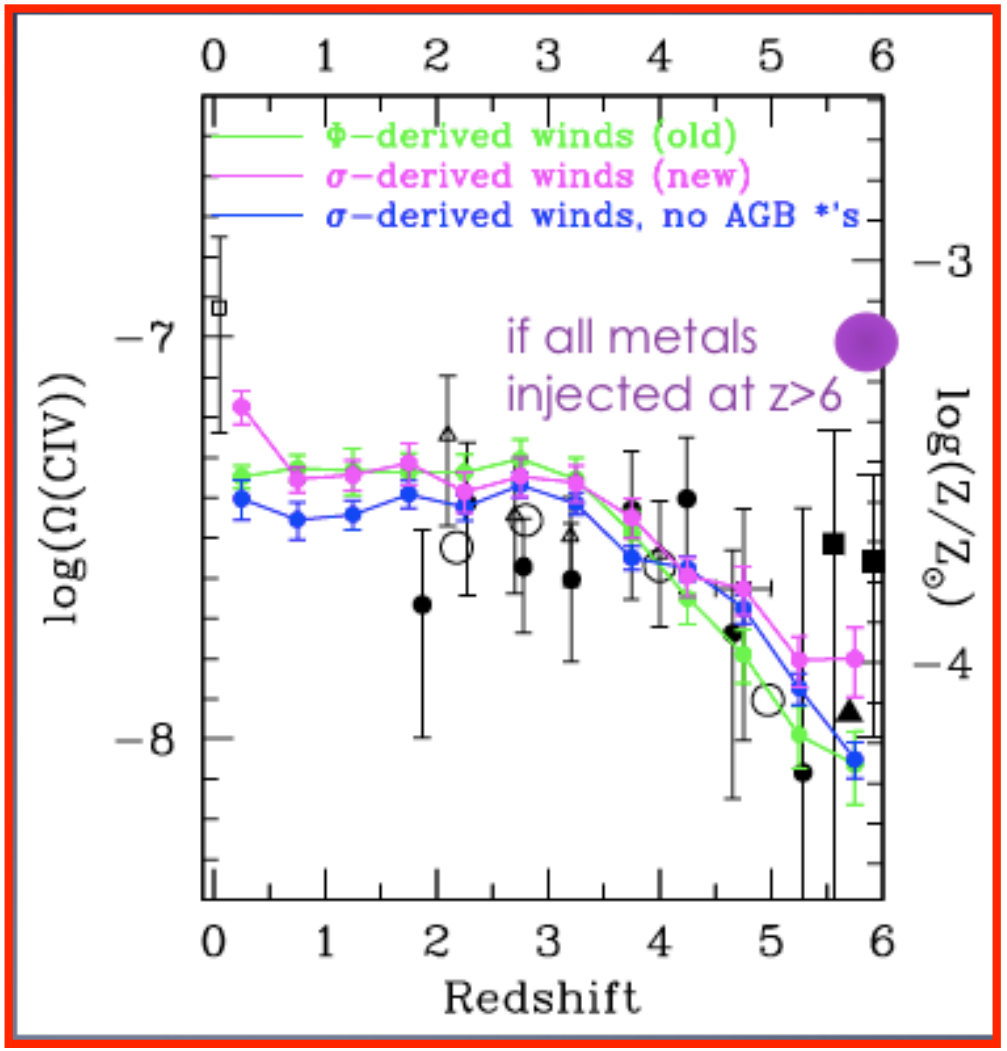
The IGM is widely enriched at high z (Pop III?).....



Songaila (2001).

The IGM is widely enriched at high z (Pop III?).....

.... High Ω_{CIV} does not imply early enrichment

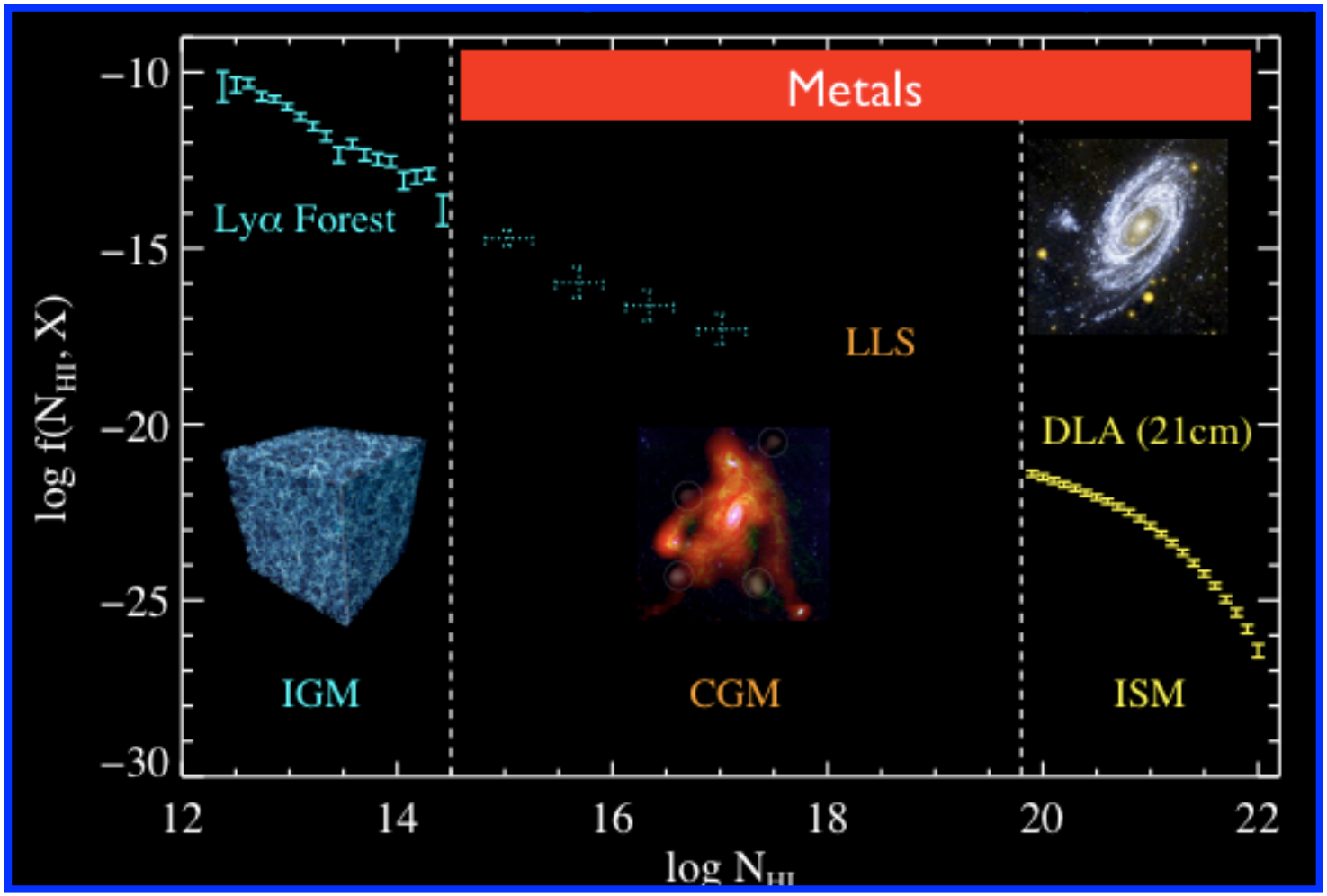


Oppenheimer, Dave.

The IGM is widely enriched at high z (Pop III?).....

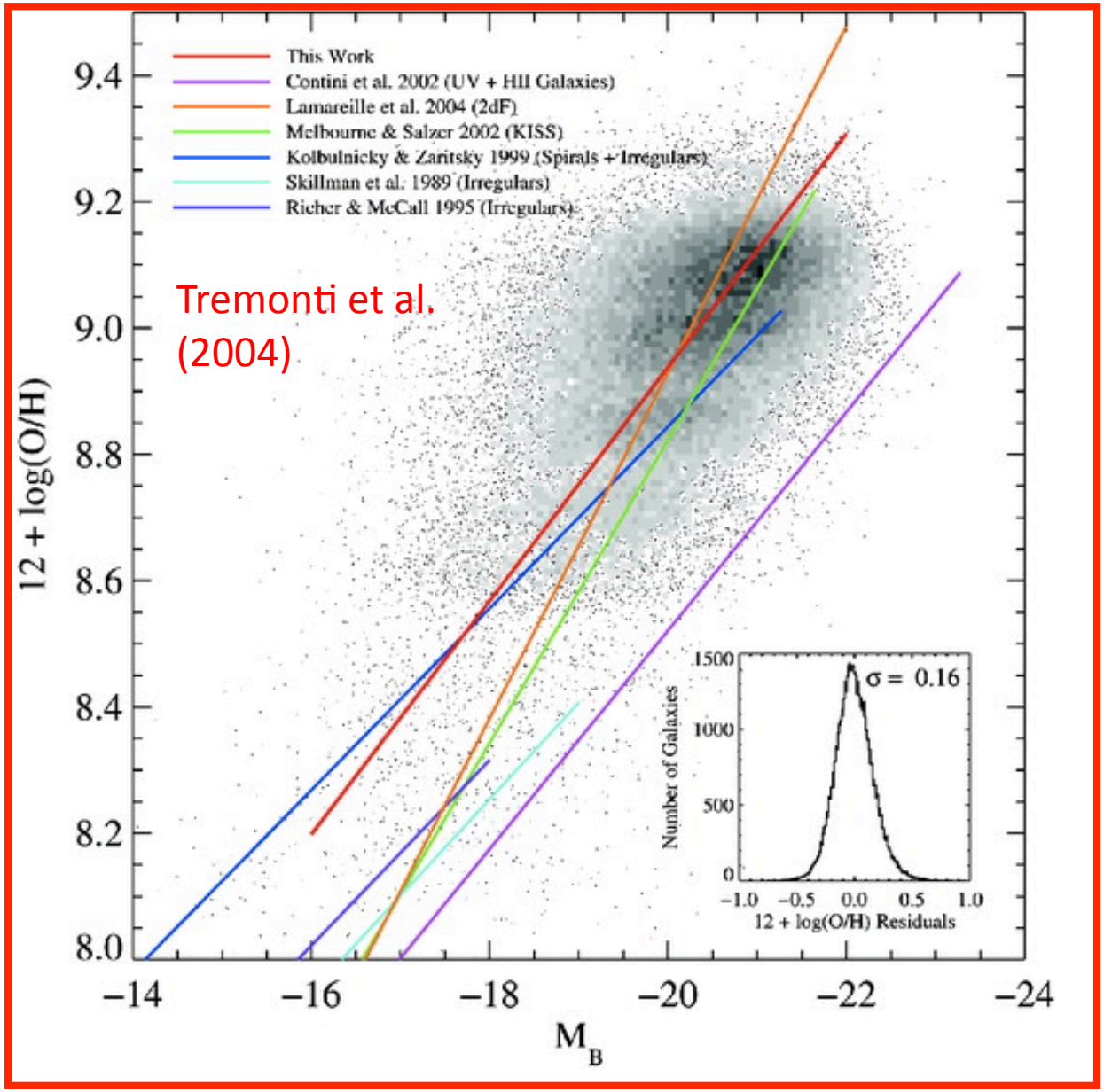
.... High Ω_{CIV} does not imply early enrichment....

.... Actually, the metals are just in galaxies.



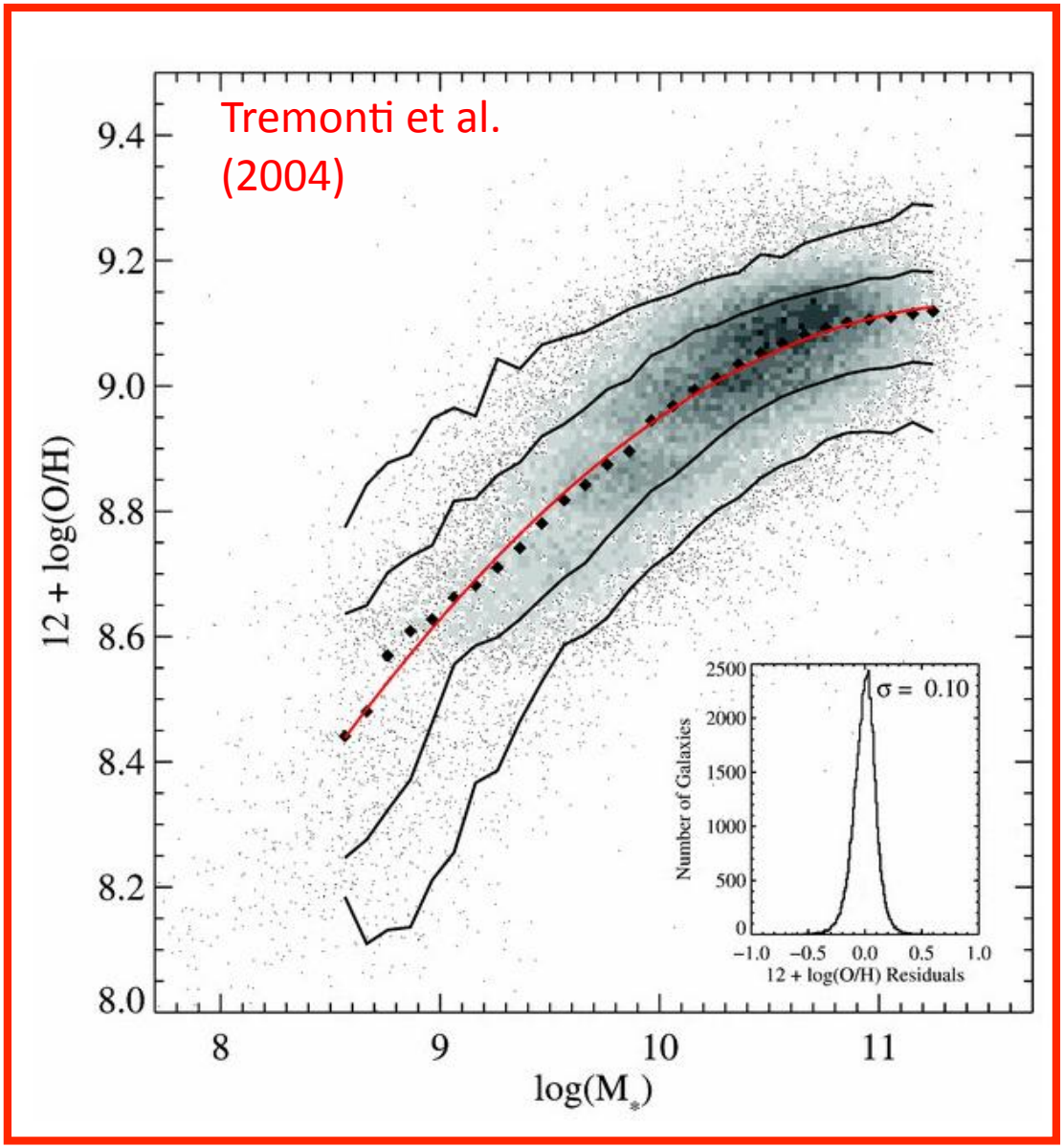
Prochaska, Dave, Oppenheimer

Luminosity-metallicity relation……



Luminosity-metallicity relation……

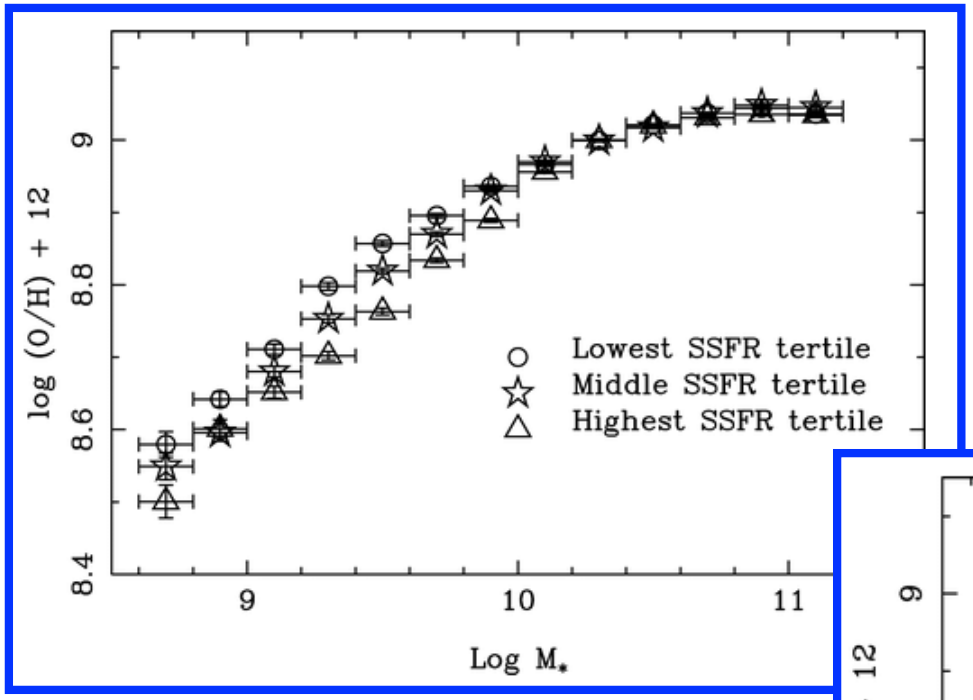
….. mass-metallicity relation…..



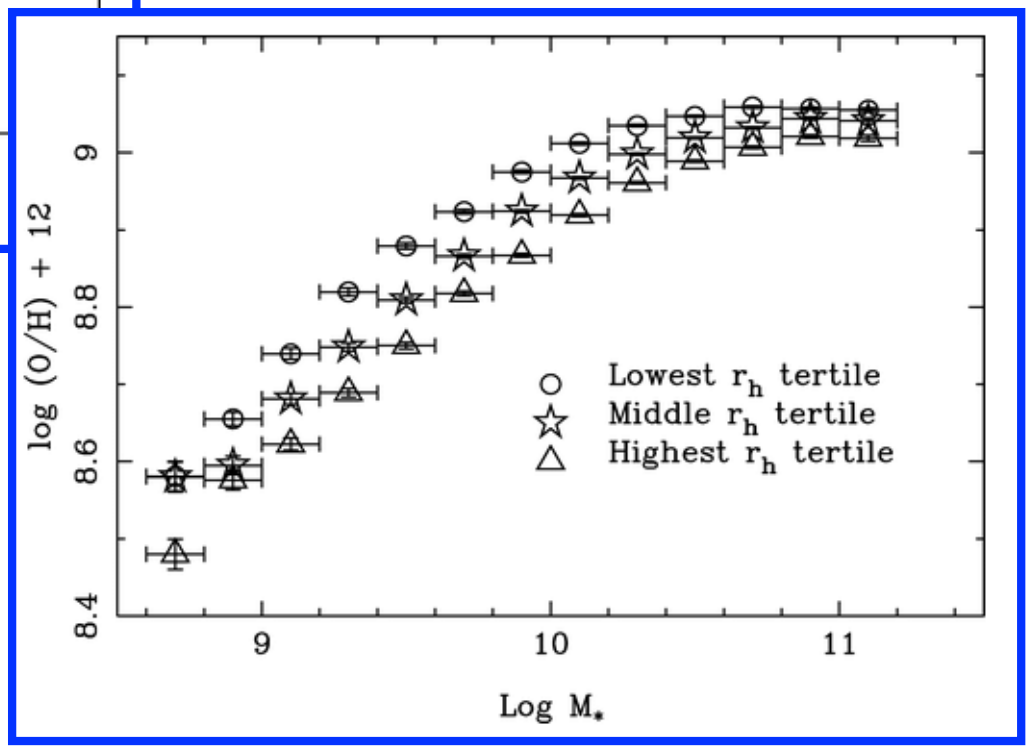
Luminosity-metallicity relation……

….. mass-metallicity relation…..

…. sequences in size and star formation rate…..



Ellison et al. (2008)



Luminosity-metallicity relation……

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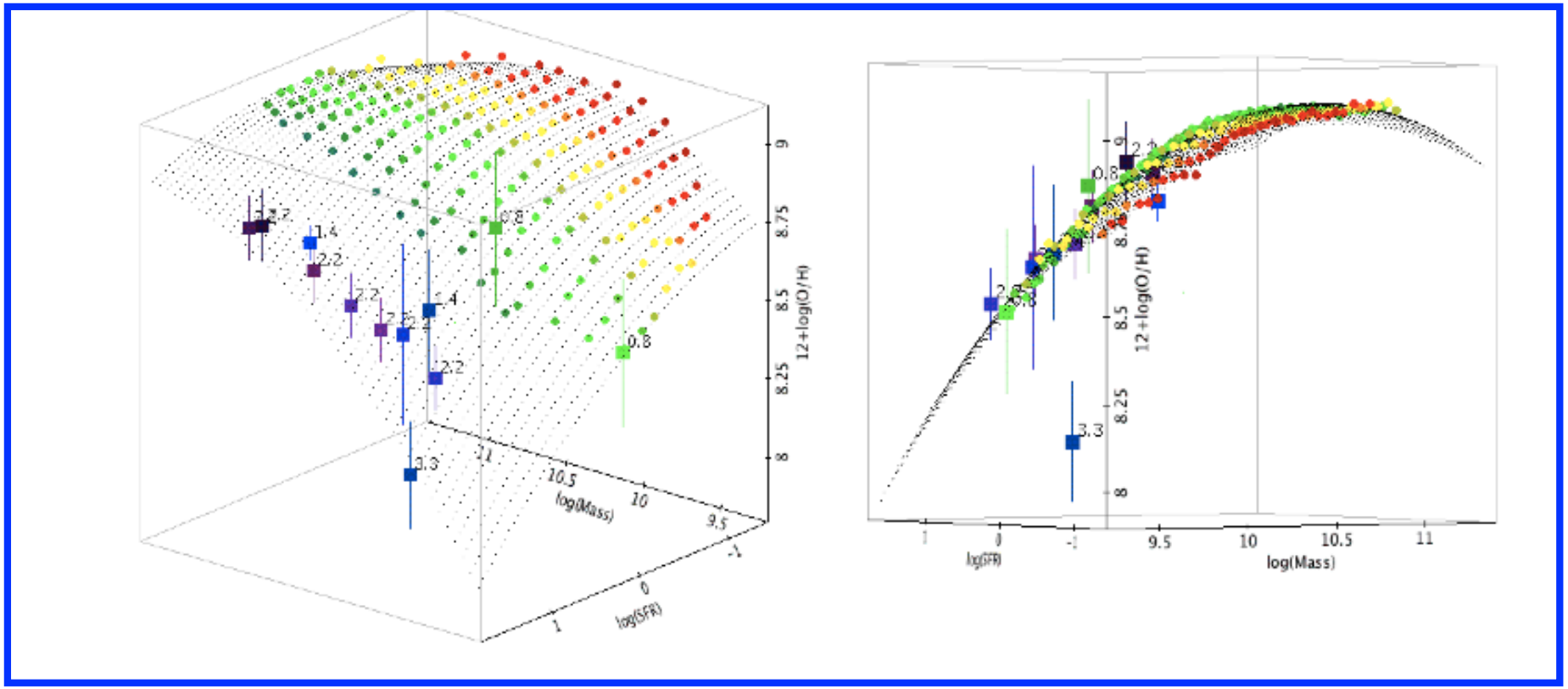
…. sequences in size and

star formation rate…..

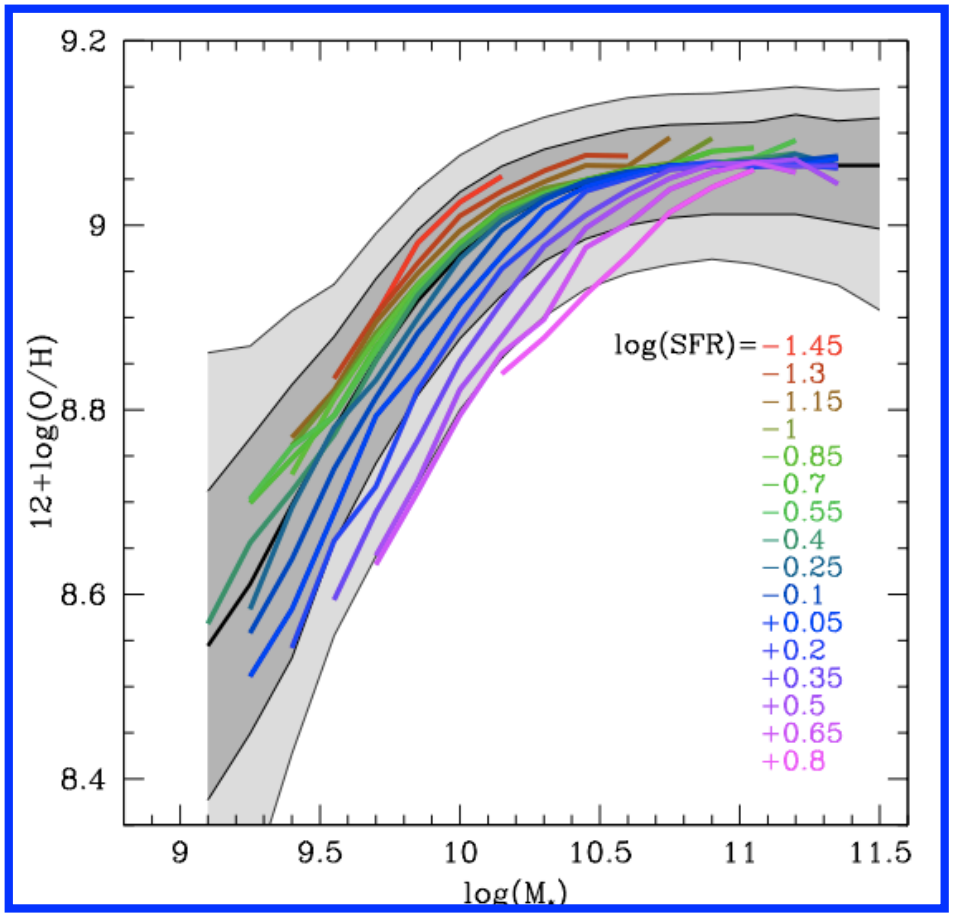


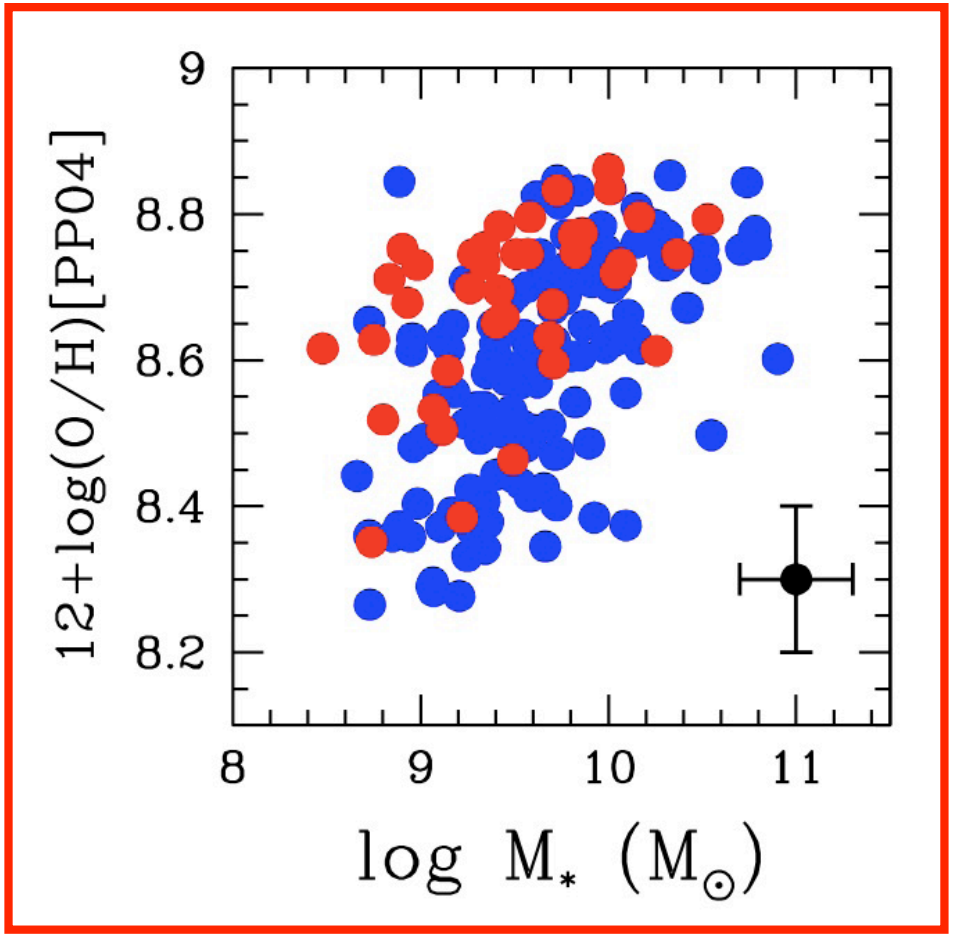
Cresci

Mannucci et al. (2010)

…. A plane in SFR-mass-metallicity (FMR).

Can this explain offsets in mass-metallicity relation, e.g. at z>0 (Cresci, but Maier), mergers (Scudder, Krabbe), clusters (Cortese), bars (Ellison, Sanchez-Blazquez, Kauffmann), population extremes (Chun)?





NATO ADVANCED RESEARCH WORKSHOP

"THE EPOCH OF GALAXY FORMATION"

UNIVERSITY OF DURHAM. U.K. JULY 18-22, 1988


Wakefield
ARMS


Wakefield
ARMS


THE
WAKEFIELD
ARMS


Wakefield
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ARMS

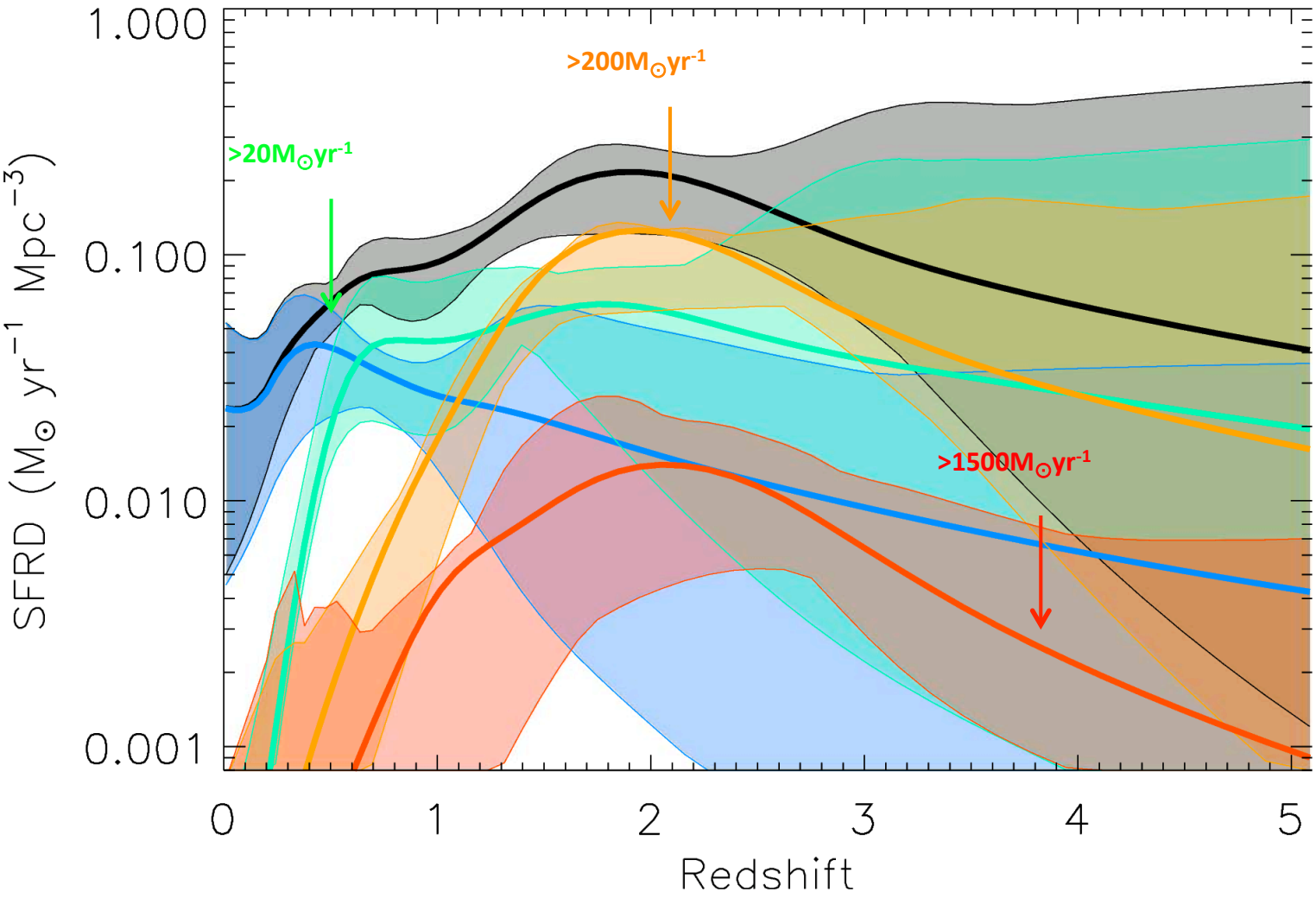
Extreme Activity

- Bursting systems (starbursts and AGN)

- Interactions between black holes and their hosts

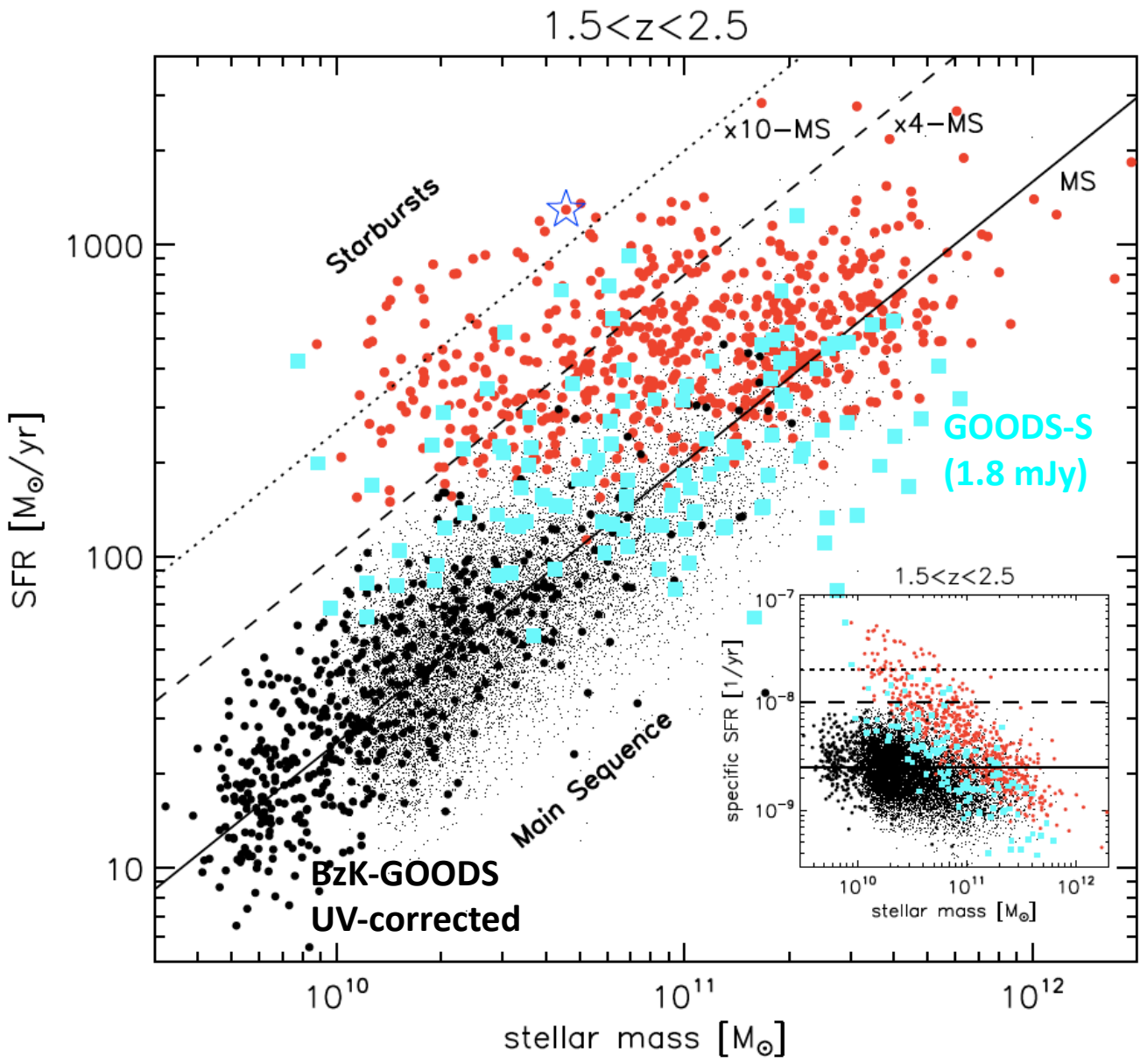
Bursting systems (starbursts and AGN)

Old view: powerful high-z SFGs are like local analogues –"bursting systems"

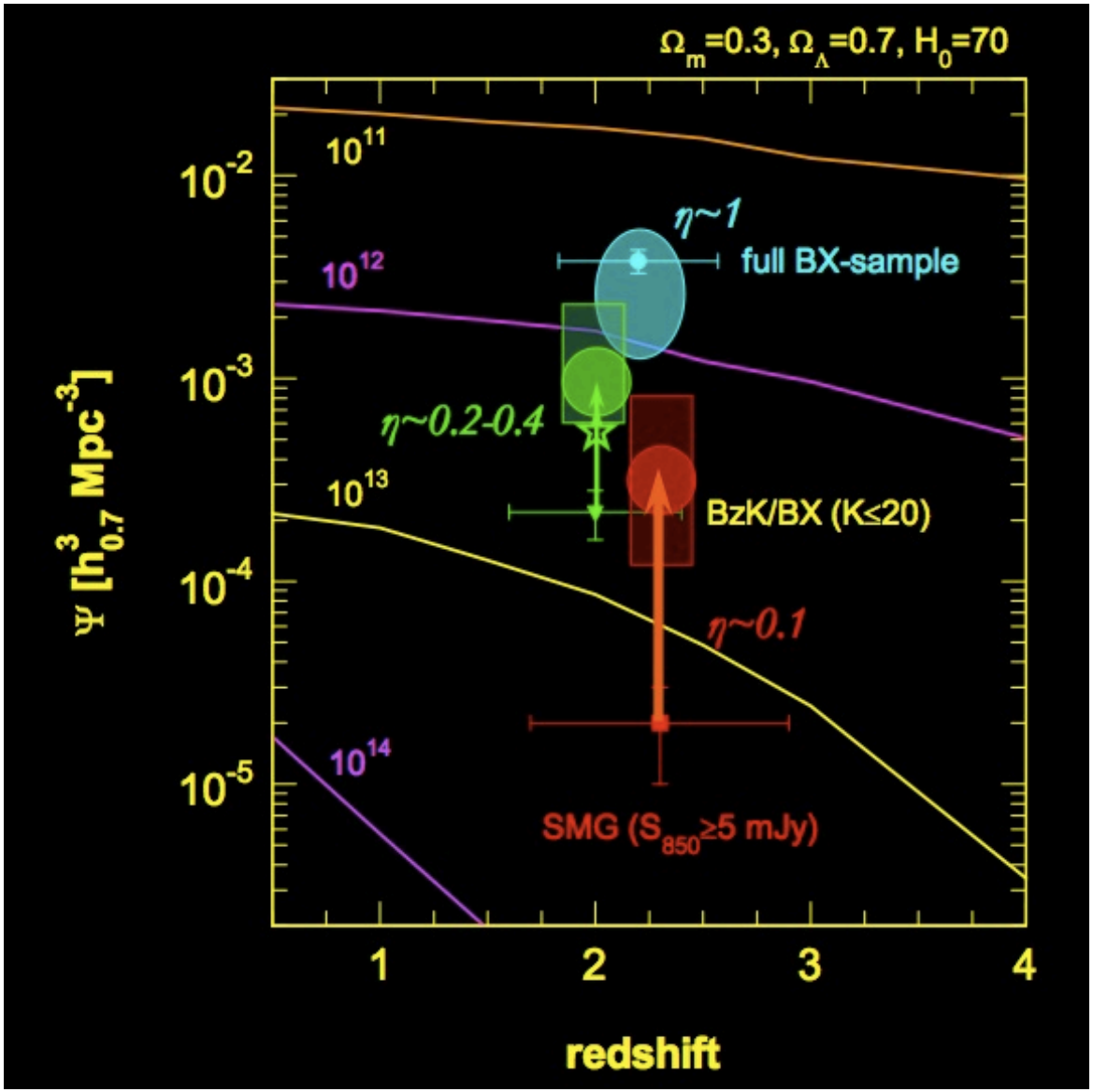


Le Borgne, Elbaz +09

New view: high-z SFGs are “quiescent” even to quite high SFRs



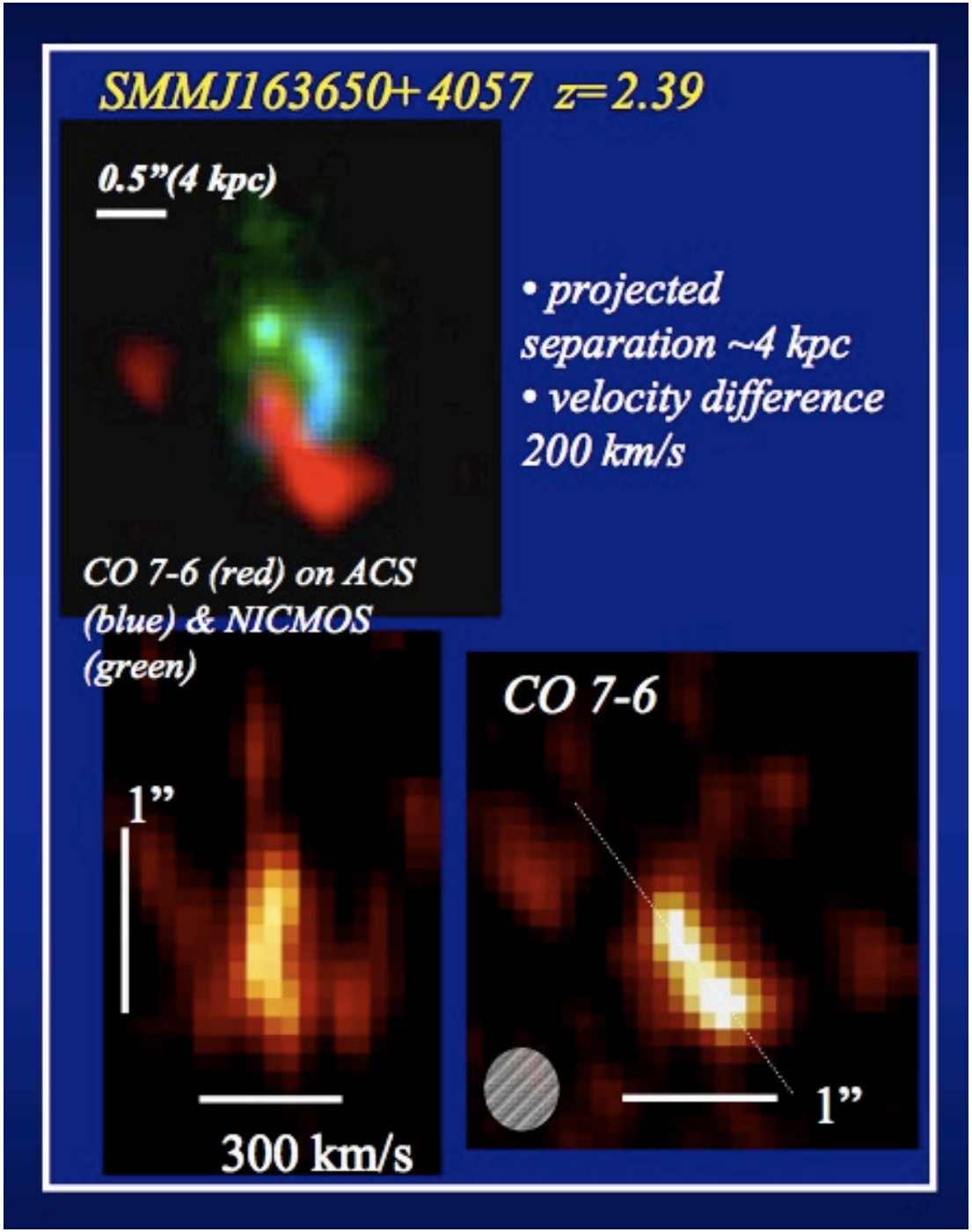
Rodighiero +11 (PEP, submitted)



High duty cycle

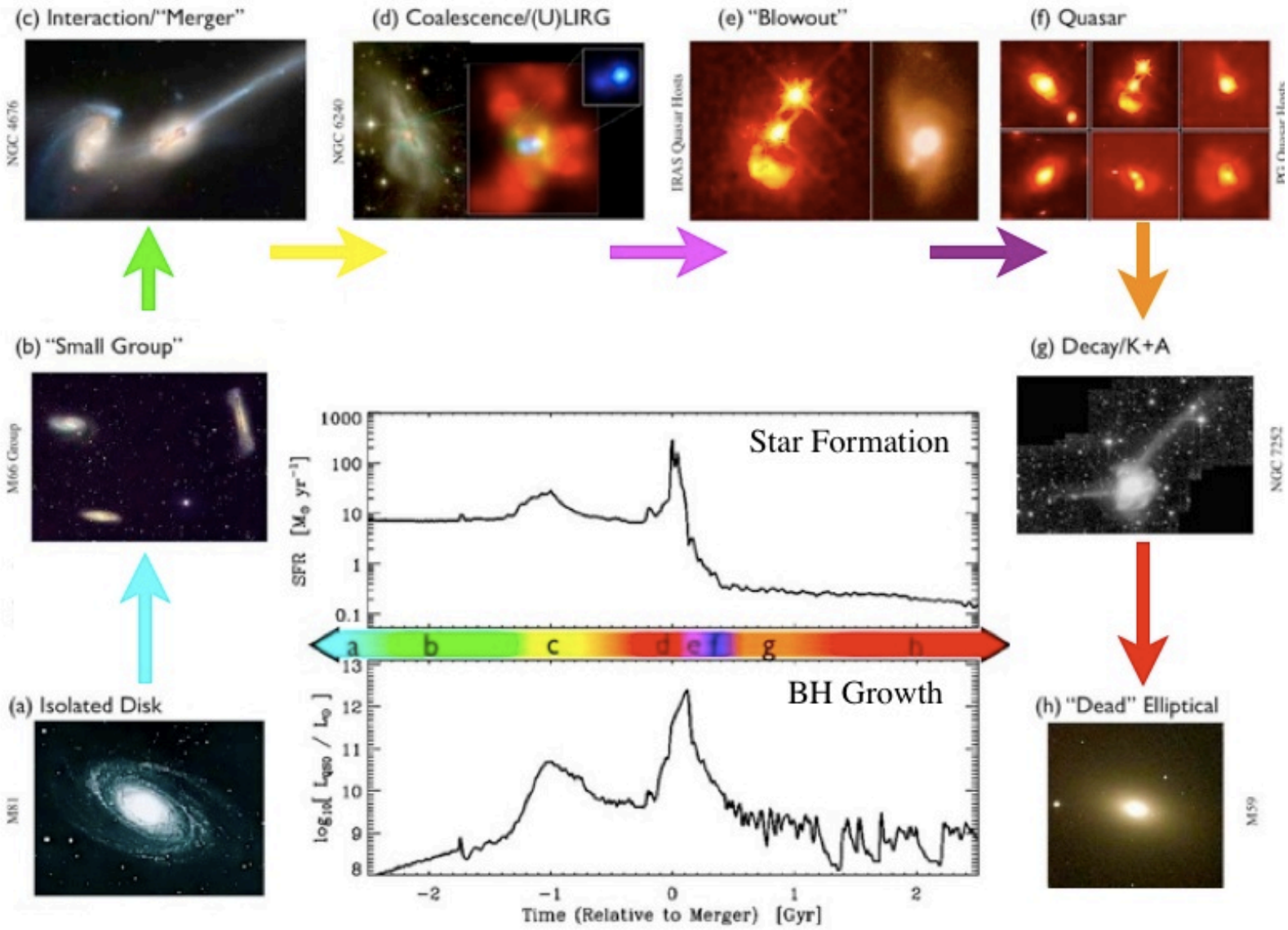
Low duty cycle
(burst)

Genzel's talk

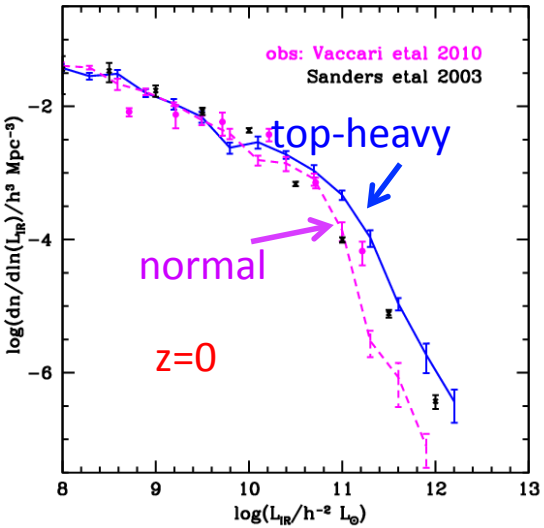


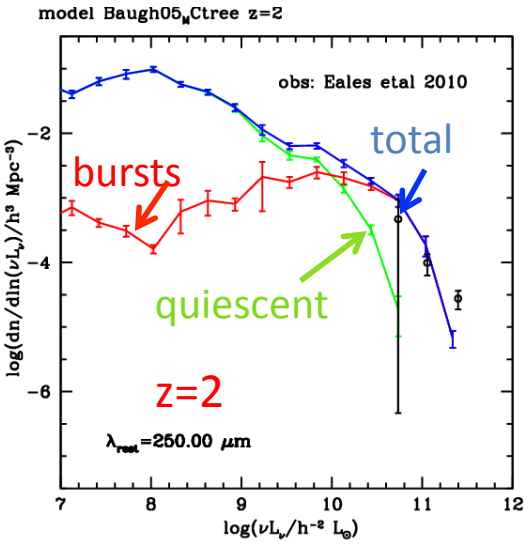
Tacconi's talk

A common triggering mechanism for starbursts and quasars? (Hopkins's talk)



Observational hints: Schawinski's talk (Treister et al.)



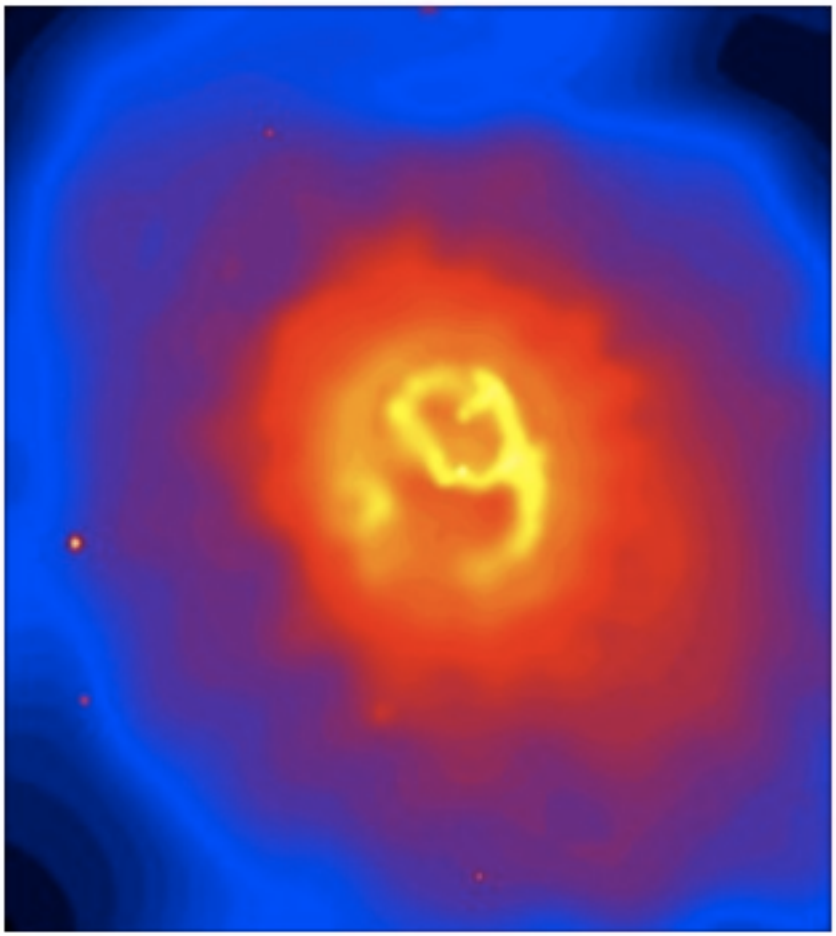


Lacey's talk

(A few) key questions:

- Does SF really proceed differently in starbursts?
- Are mergers the main triggering mechanism?
- Where does the transition between "quiescent" and "bursting" really occur?
- Is this directly linked to AGN fueling? Is there an evolutionary sequence between starbursts and quasars (esp. at high z)?

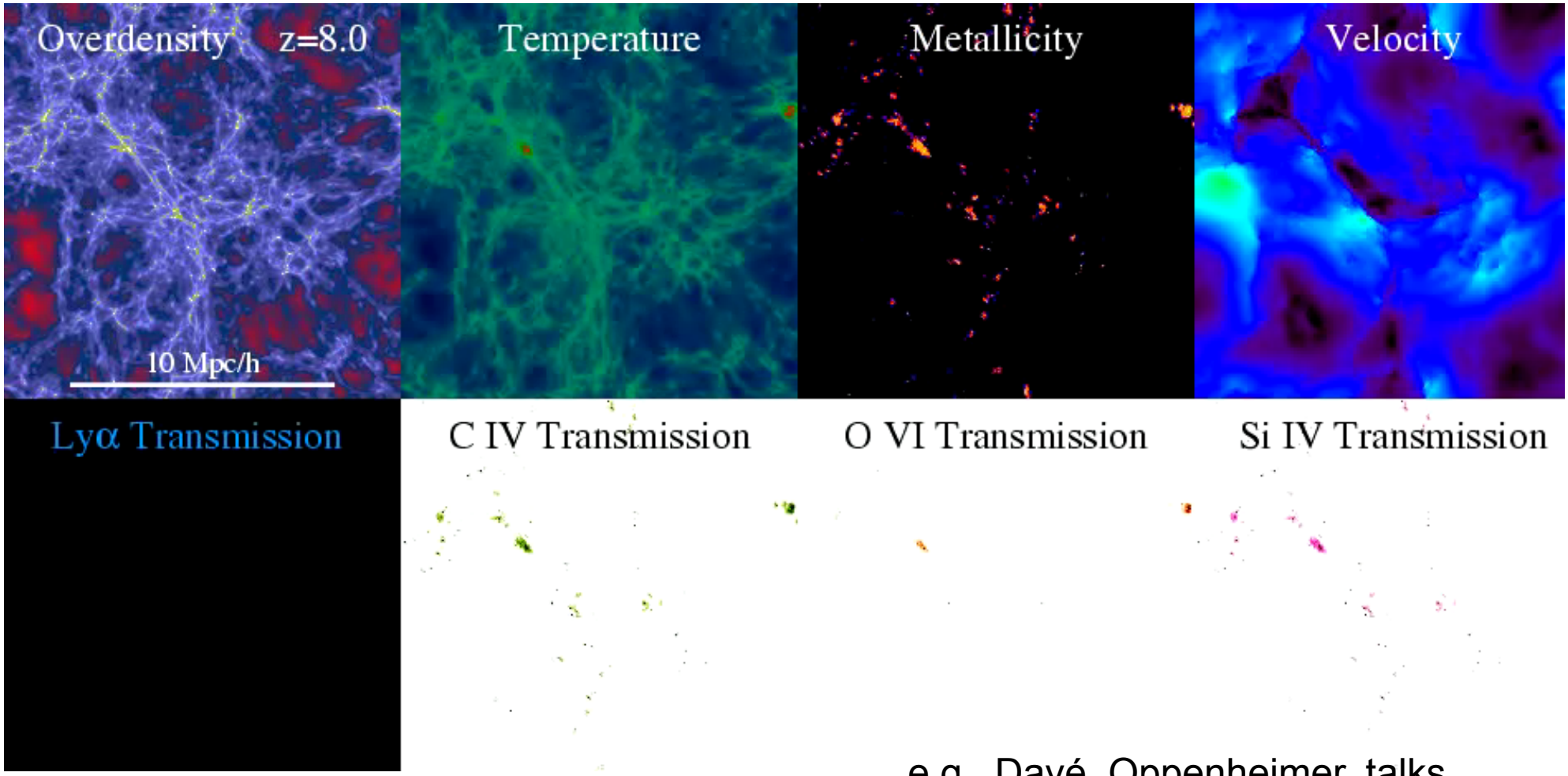
Interactions between black holes and their hosts



Donoso et al (2010)

Old view: Black holes not important?

Old view: Black holes not important?



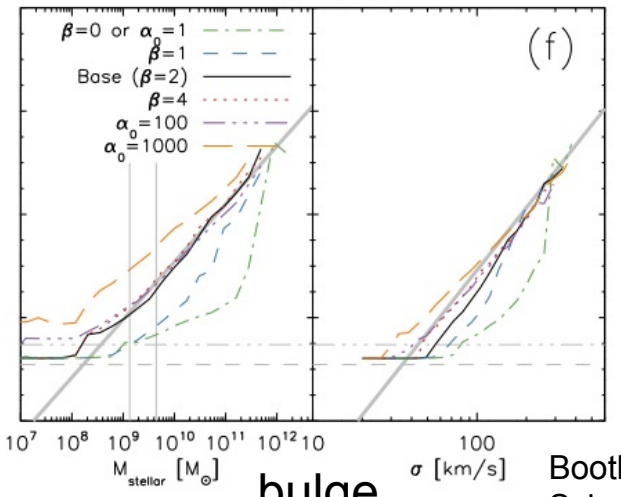
e.g., Davé, Oppenheimer, talks

"I'm banned from telescopes for the most part" -- Davé

New-(ish) view: Black holes might be *very* important

Black holes

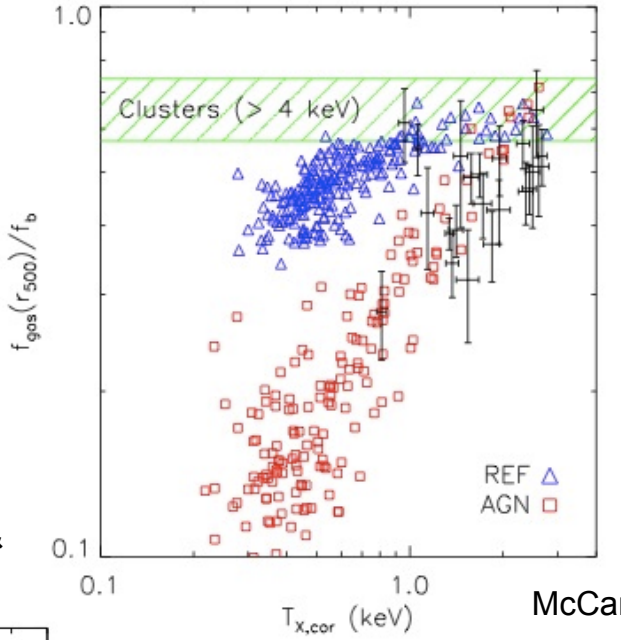
Black hole



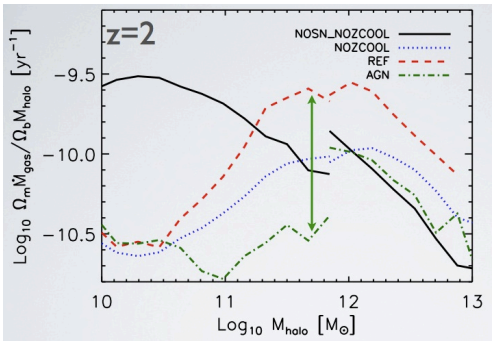
bulge

Booth & Schaye

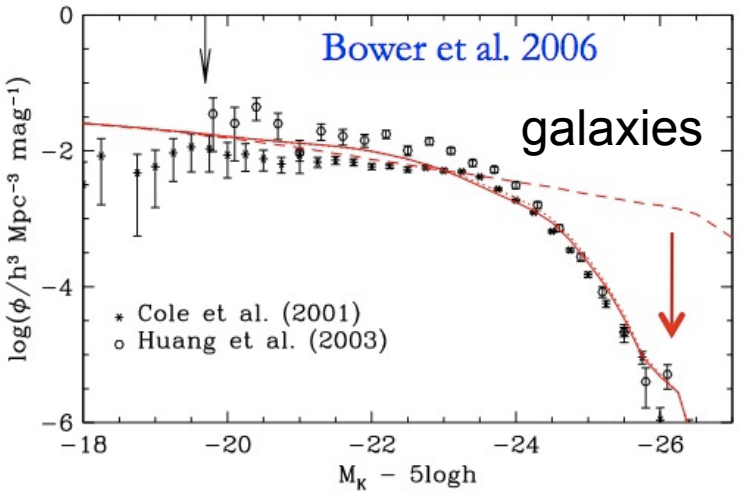
groups



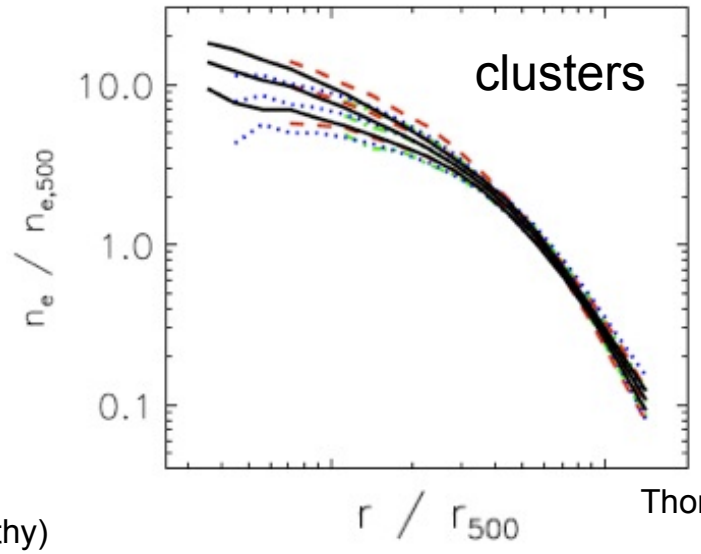
McCarthy



Van de Voort



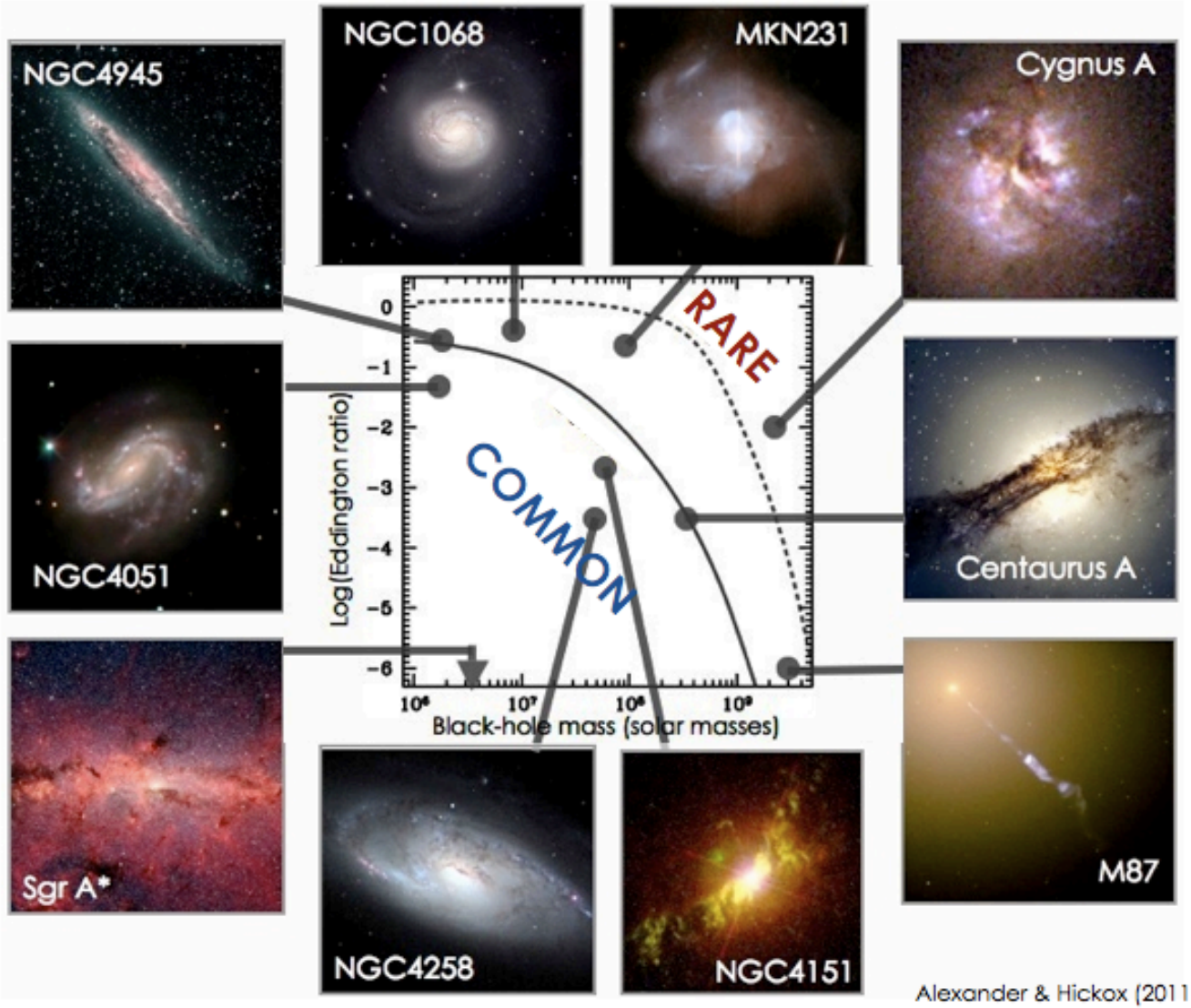
Fanidakis



Thomas

Also abundance profiles in the ICM/etc. (McCarthy)

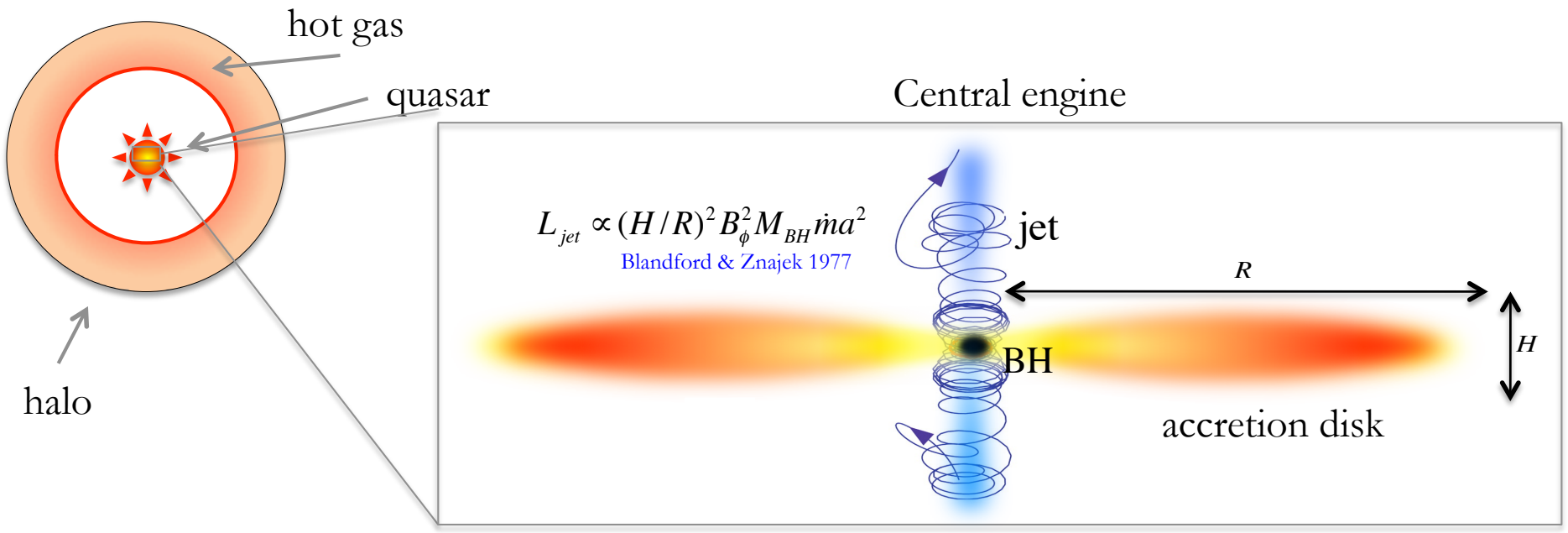
New-(and old) view: AGN (and feedback) take many forms

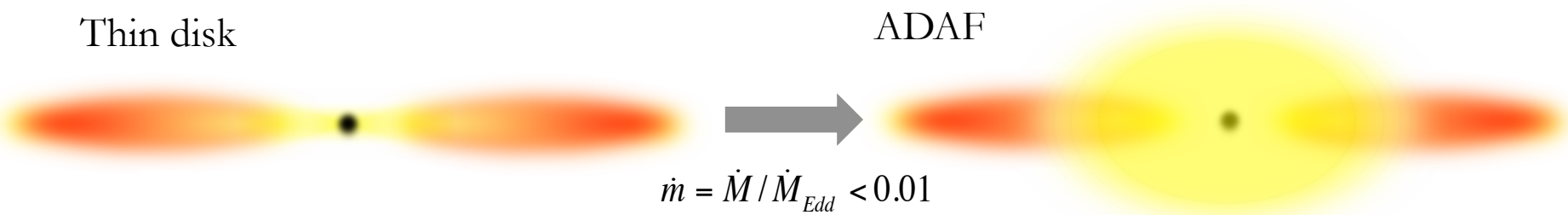


Alexander & Hickox (2011) to appear in *New Astronomy Reviews*

Black hole accretion modes

Fanidakis, Heckman





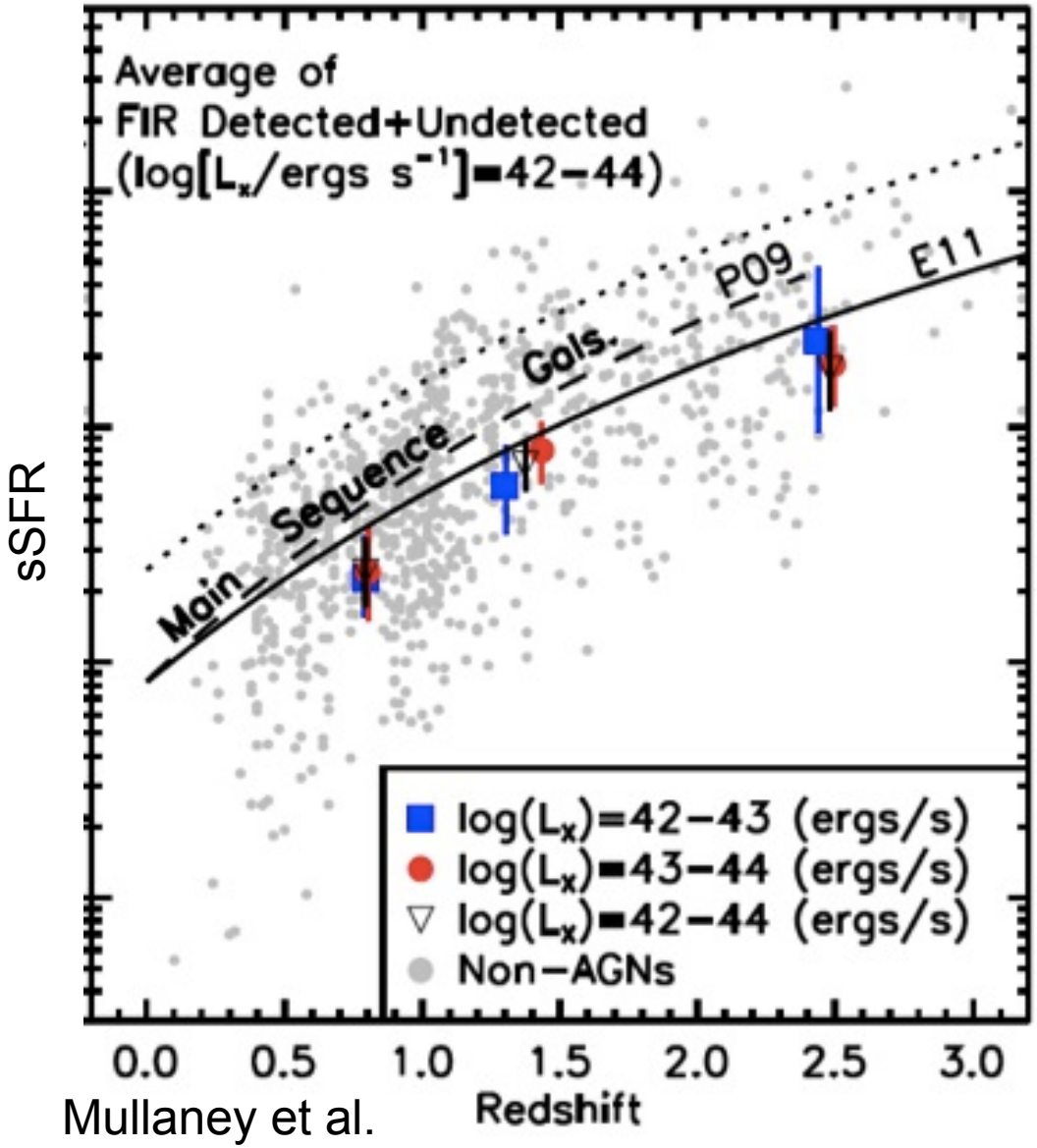
luminous disks
weak jets

under-luminous disks
strong jets

"Quasars"

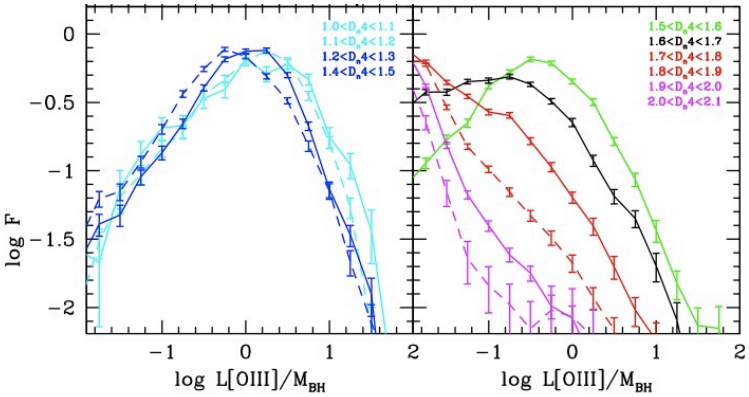
"Radio galaxies"

Moderate-level accretion appears to occur in non-merging systems and are naturally associated with **star formation**

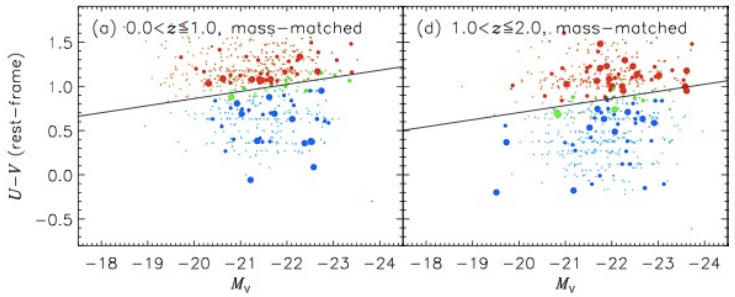


Mullaney et al.

Heckman, Mullaney, Alexander, Schawinski



Kauffmann & Heckman

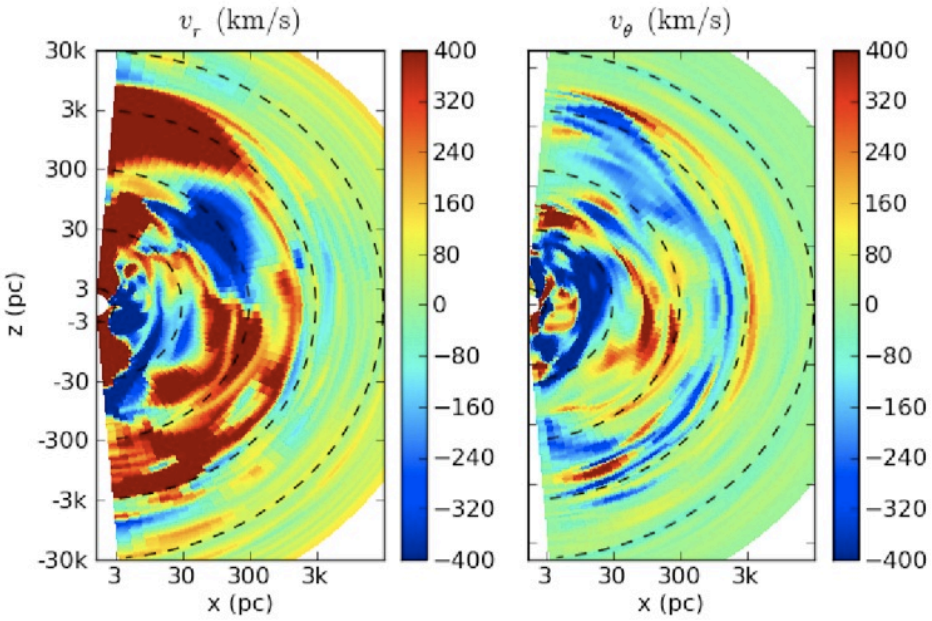


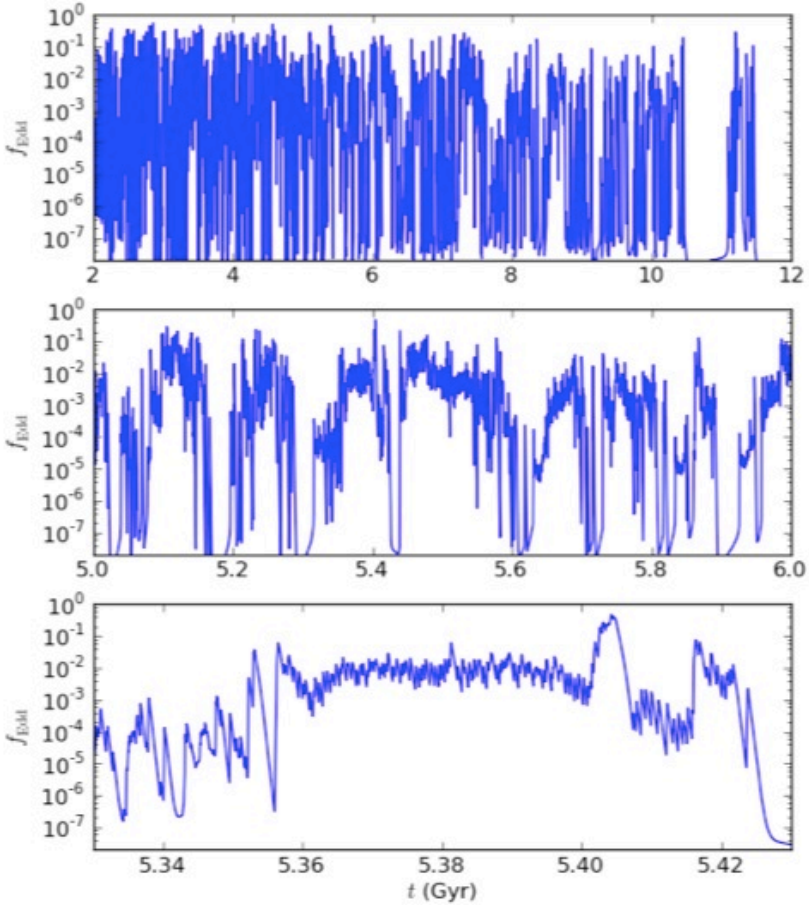
Xue et al., Alexander's talk

Little difference between AGN hosts and non-AGN

Accretion is **messy** and **stochastic**

Novak's talk





"No respectable theorist would touch this…

Thankfully we have a lot of "not-so-respectable" theorists" -- Steidel

McNamara's talk

X-ray

Abell 2052

Chandra 500 ksec unsmoothed

2nd shock

1st shock

N filament

E~10^{59} erg

Blanton + 11

NW loop

N bubble

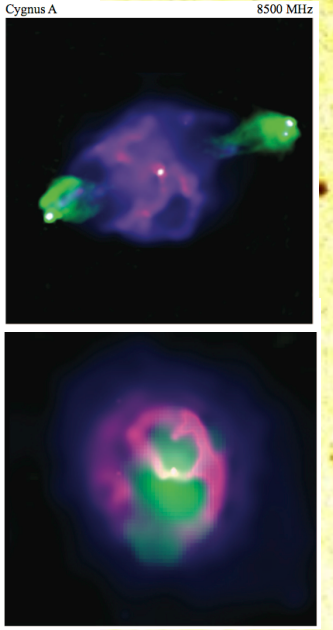
NW bubble

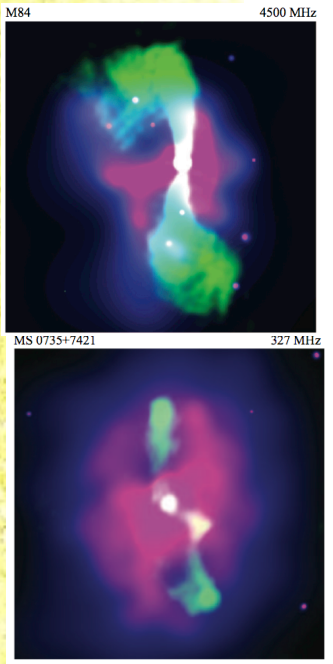
S bubble

SE outer bubble

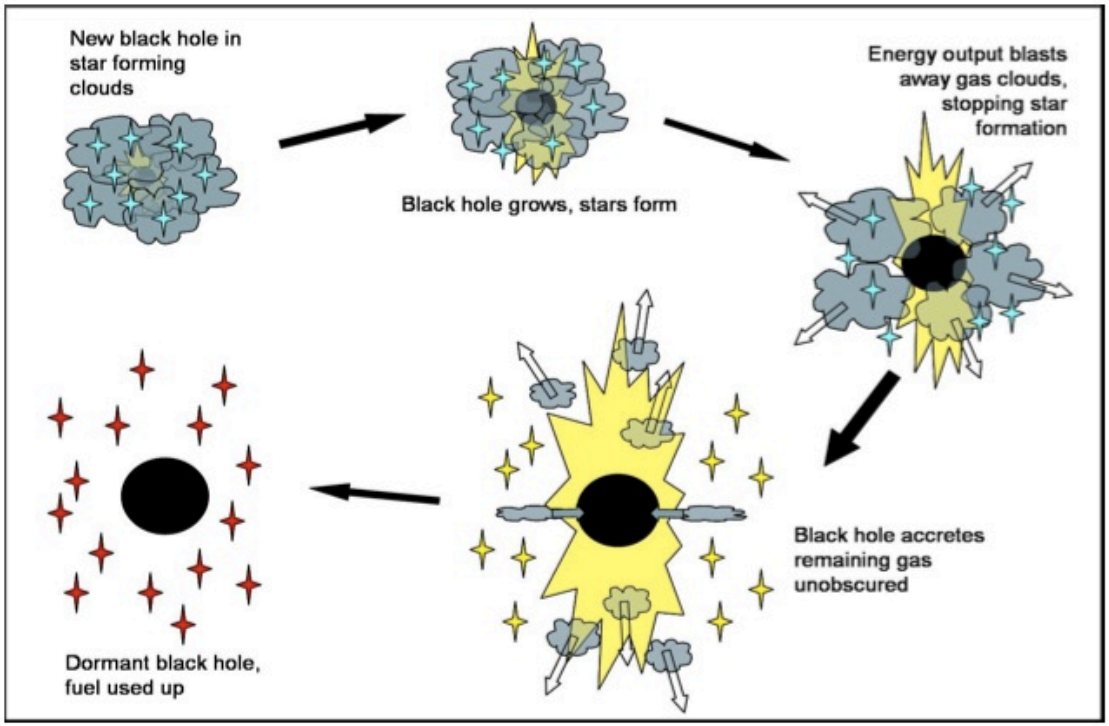
visual

30 kpc





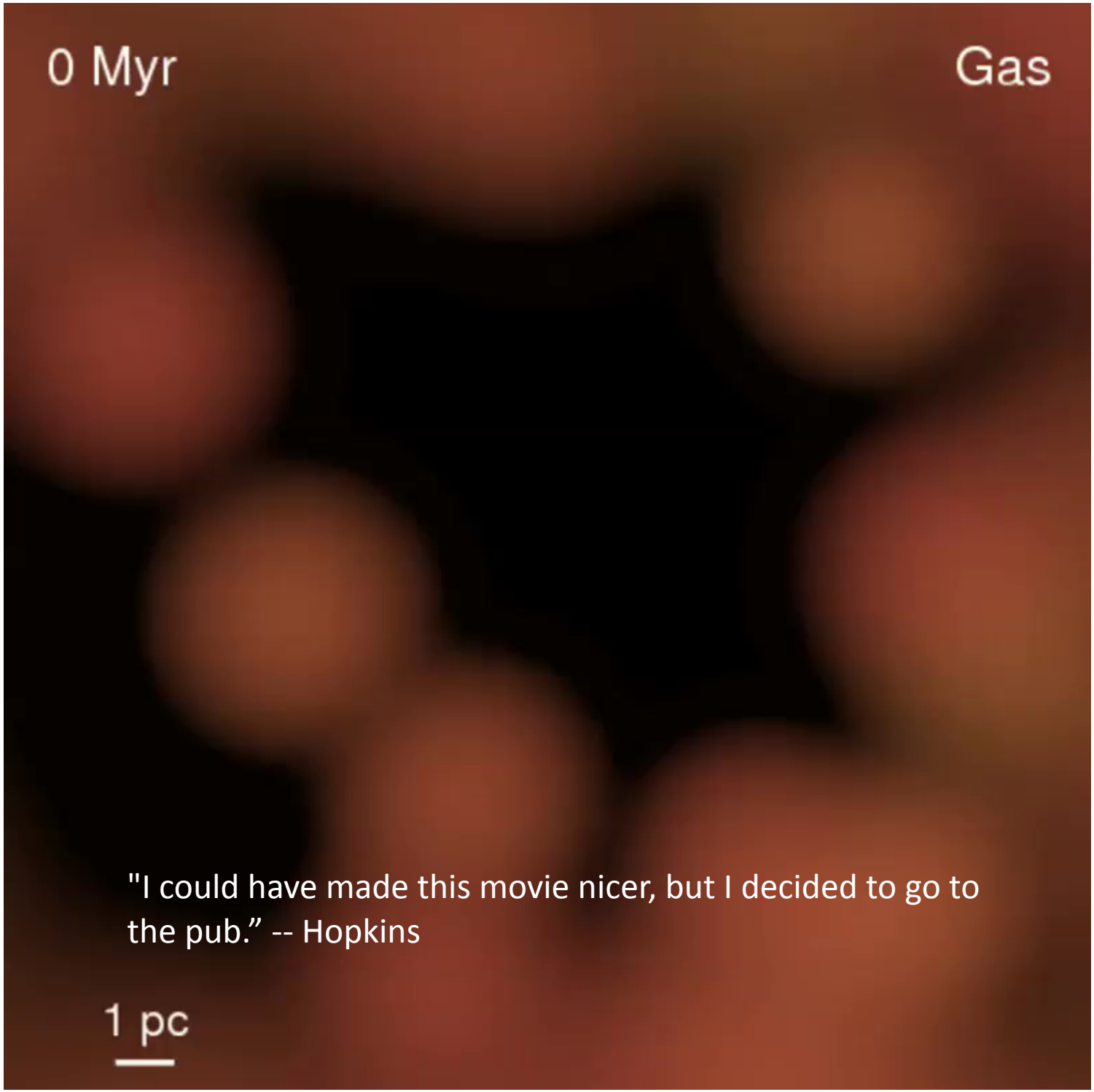
Radiatively-driven feedback expels gas from the galaxy?



Kauffmann's talk

Dominant mode of AGN energy input? (e.g. Hopkins)

Some observational evidence for galaxy-scale quasar outflows (Alexander's talk)


0 Myr
Gas
"I could have made this movie nicer, but I decided to go to the pub.” -- Hopkins
1 pc

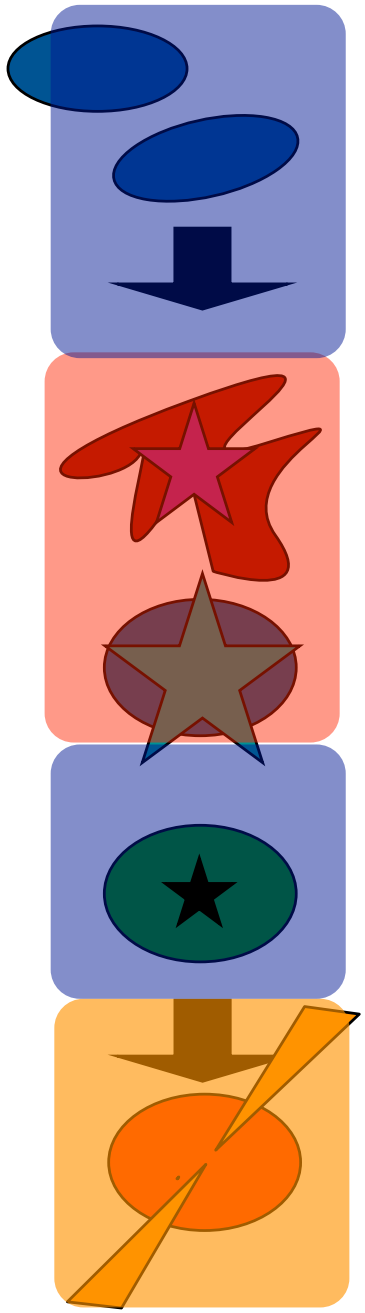
Gas-rich galaxy(s)

Cosmic time

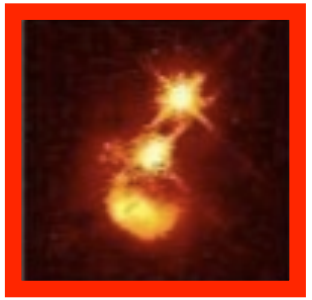
Starburst galaxy

Quasar

Red sequence galaxy



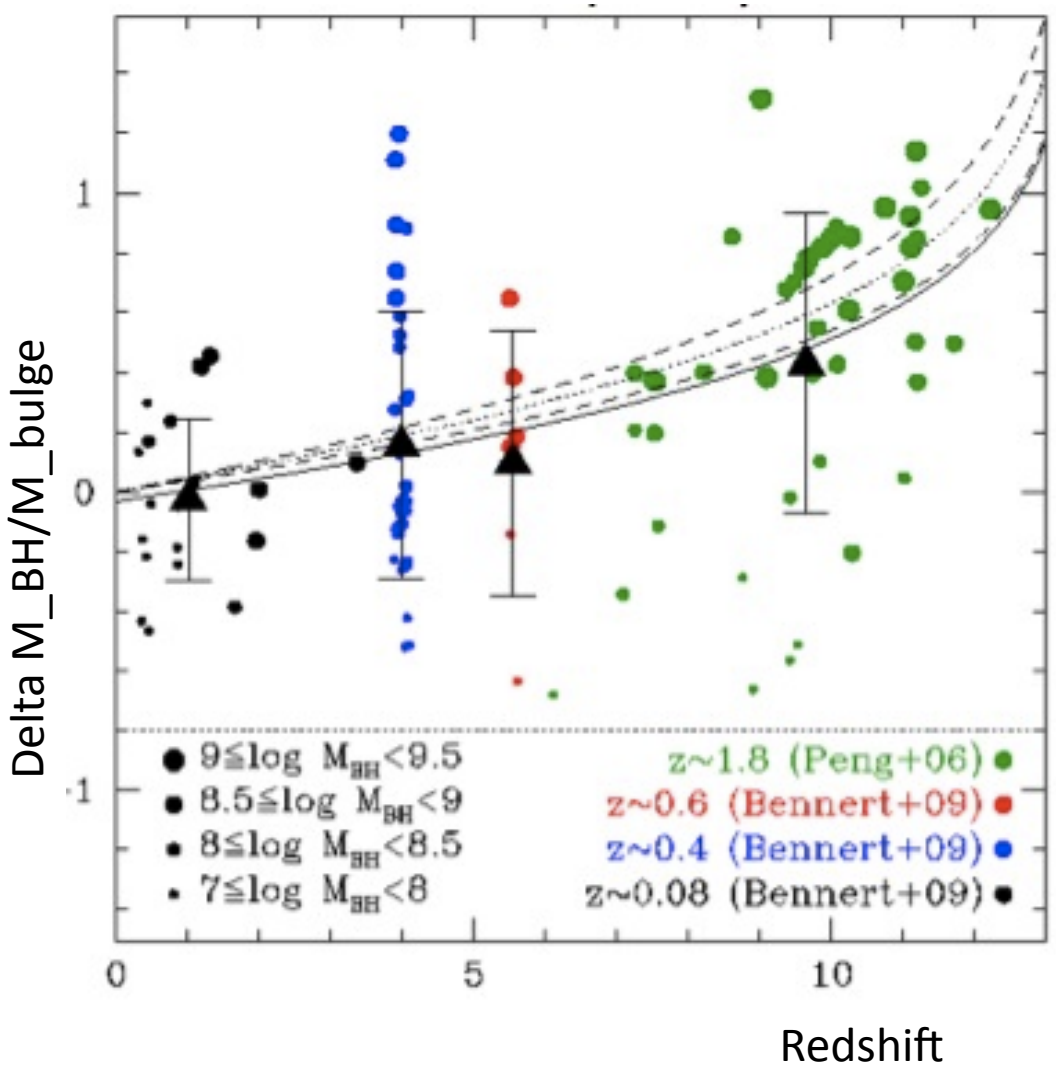
Radiative or mechanical feedback significantly affects the host



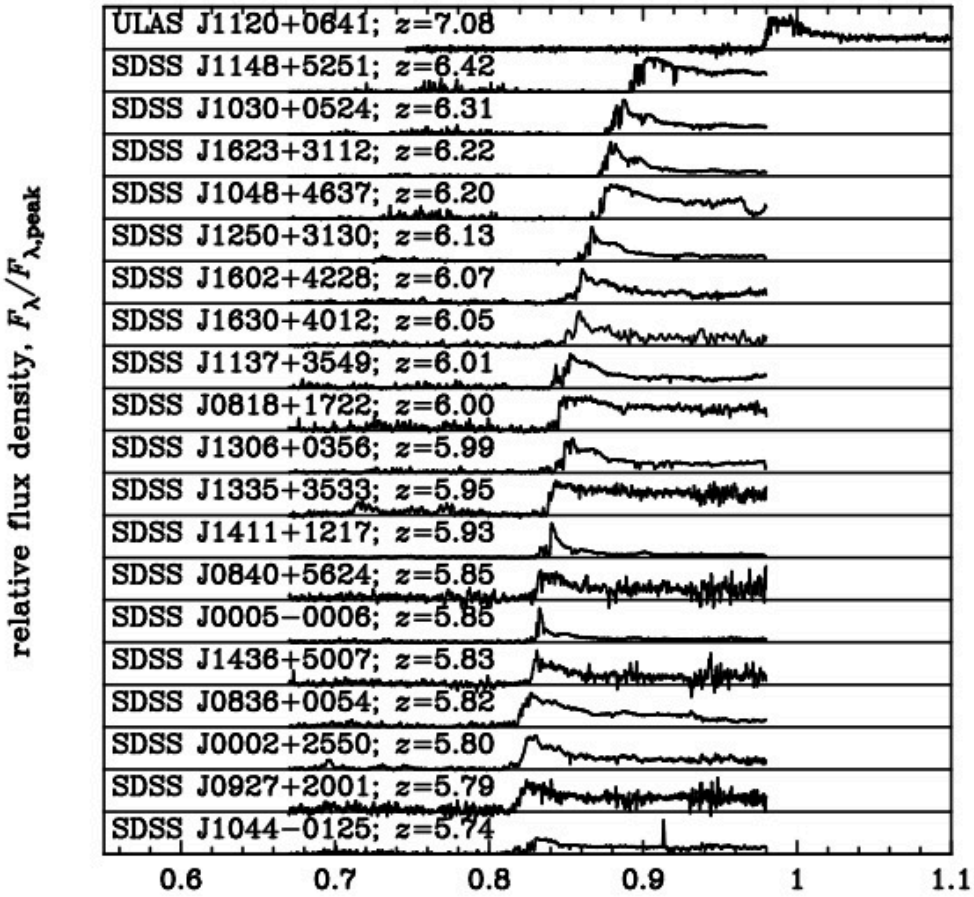
Black hole self-regulation?

How do the masses of black holes and galaxies evolve?

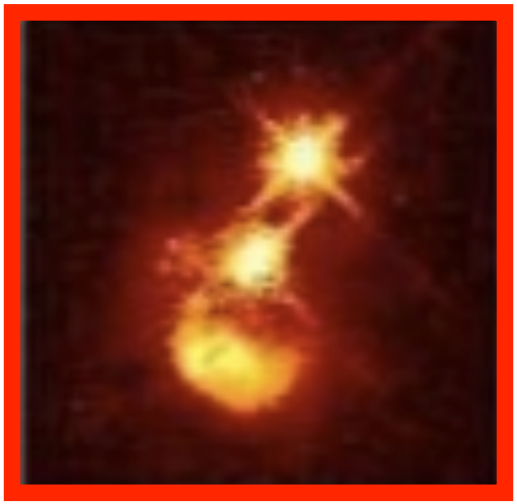
Bennert's talk



How to make the first quasars?



High BH mass at z > 7, although rare (Mortlock), but hard to make in simulations (Abel)



(A few) key questions:

- How exactly does AGN radiative or mechanical luminosity couple to gas? How do we properly model this in simulations?
- What is the abundance of galaxy-scale, radiatively-driven quasar outflows?
- Do AGN really govern the entropy in groups at high redshift? What mode of AGN are these?
- How are the first “seed” black holes produced? Do BHs grow faster or slower (on average) than their hosts?

Doktor Professor

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50:50

15	Rs 1 crore
14	50,00,000
13	25,00,000
12	12,50,000
11	6,25,000
10	3,20,000
9	1,60,000
8	80,000
7	40,000
6	20,000
5	10,000
4	5,000
3	3,000
2	2,000
1	1,000

Which is the 5th planet in solar system?

- A: Jupiter
- B: Mars
- C: Uranus

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15	Rs 1 crore
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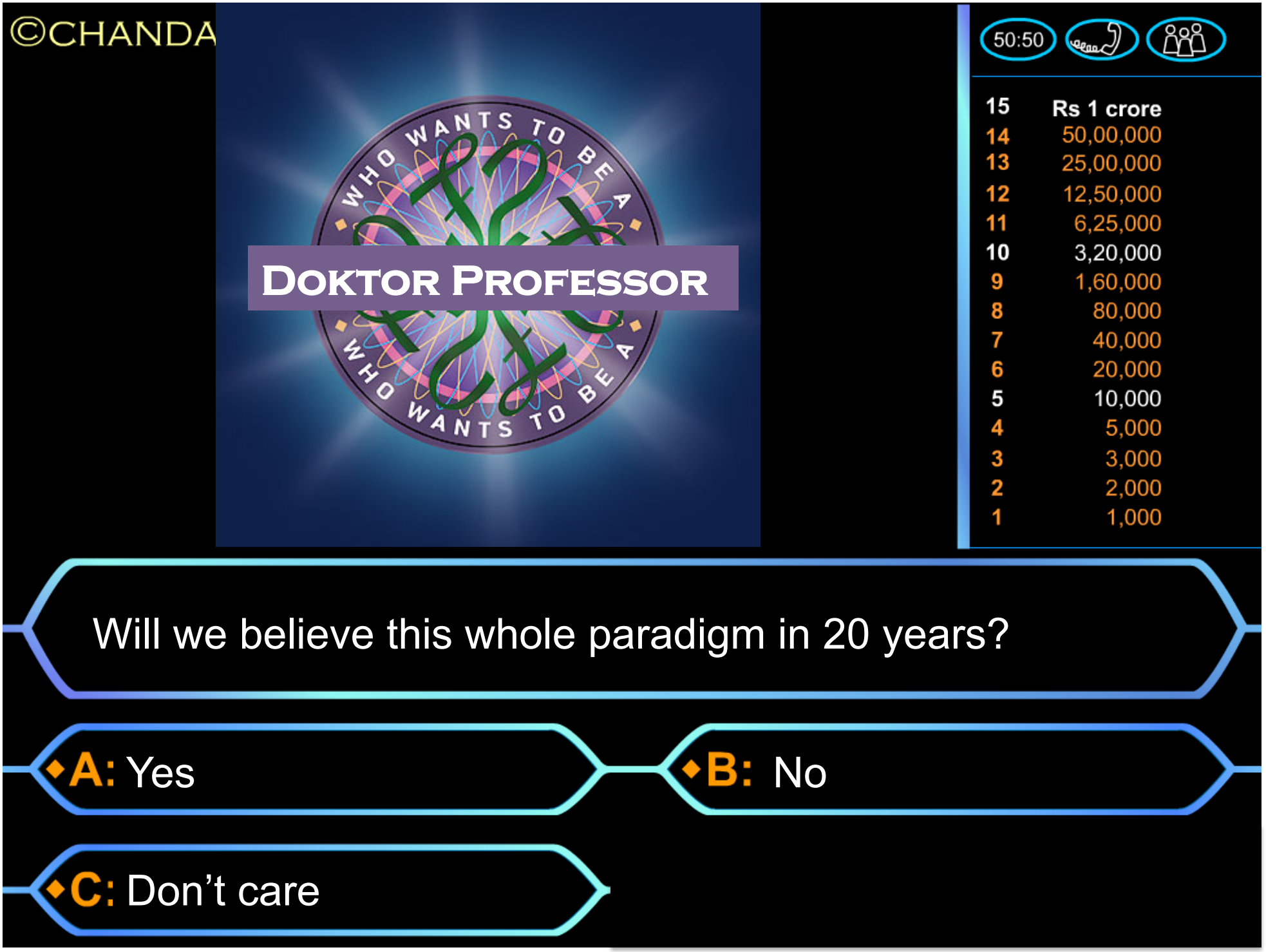
8	80,000
7	40,000
6	20,000
5	10,000
4	5,000
3	3,000
2	2,000
1	1,000

What is the dominant gas supply for star formation?

- **A:** Halo accretion
- **B:** Cold flows
- **C:** Mergers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50:50
15 Rs 1 crore
14 50,00,000
13 25,00,000
12 12,50,000
11 6,25,000
10 3,20,000
9 1,60,000
8 80,000
7 40,000
6 20,000
5 10,000
4 5,000
3 3,000
2 2,000
1 1,000
Will we believe this whole paradigm in 20 years?
A: Yes
B: No
C: Don’t care