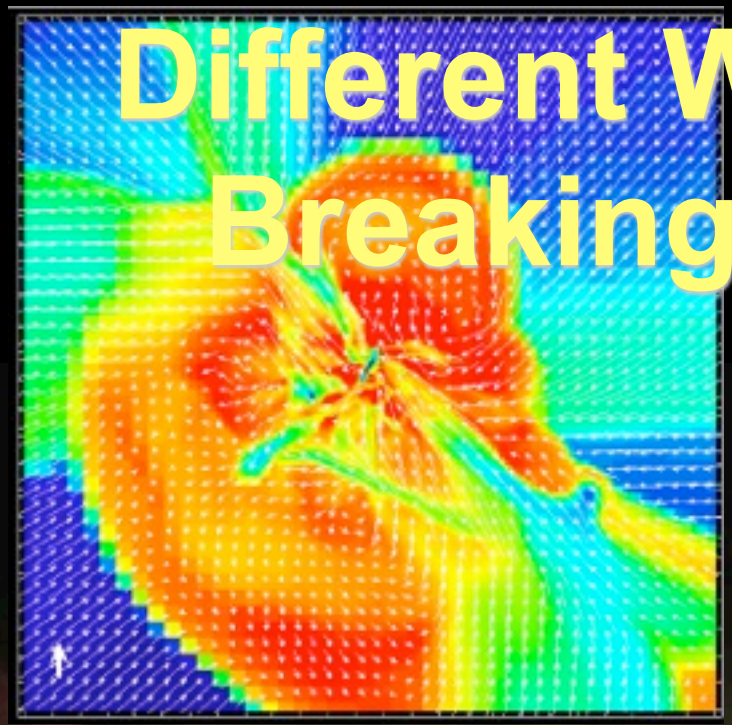
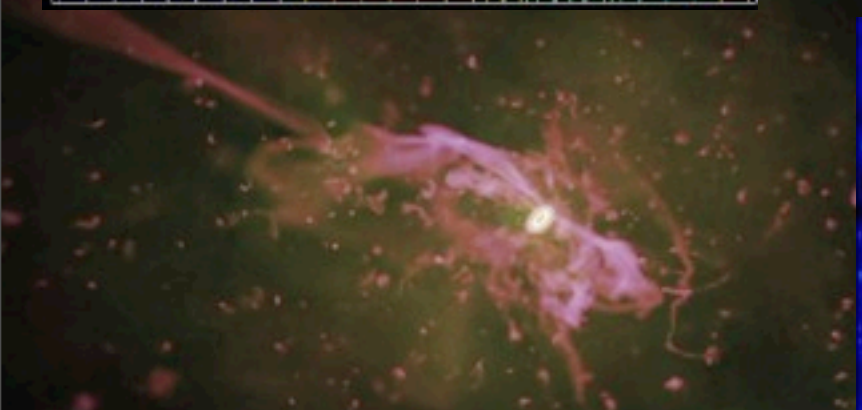
Different Ways to Quench: Breaking Degeneracies



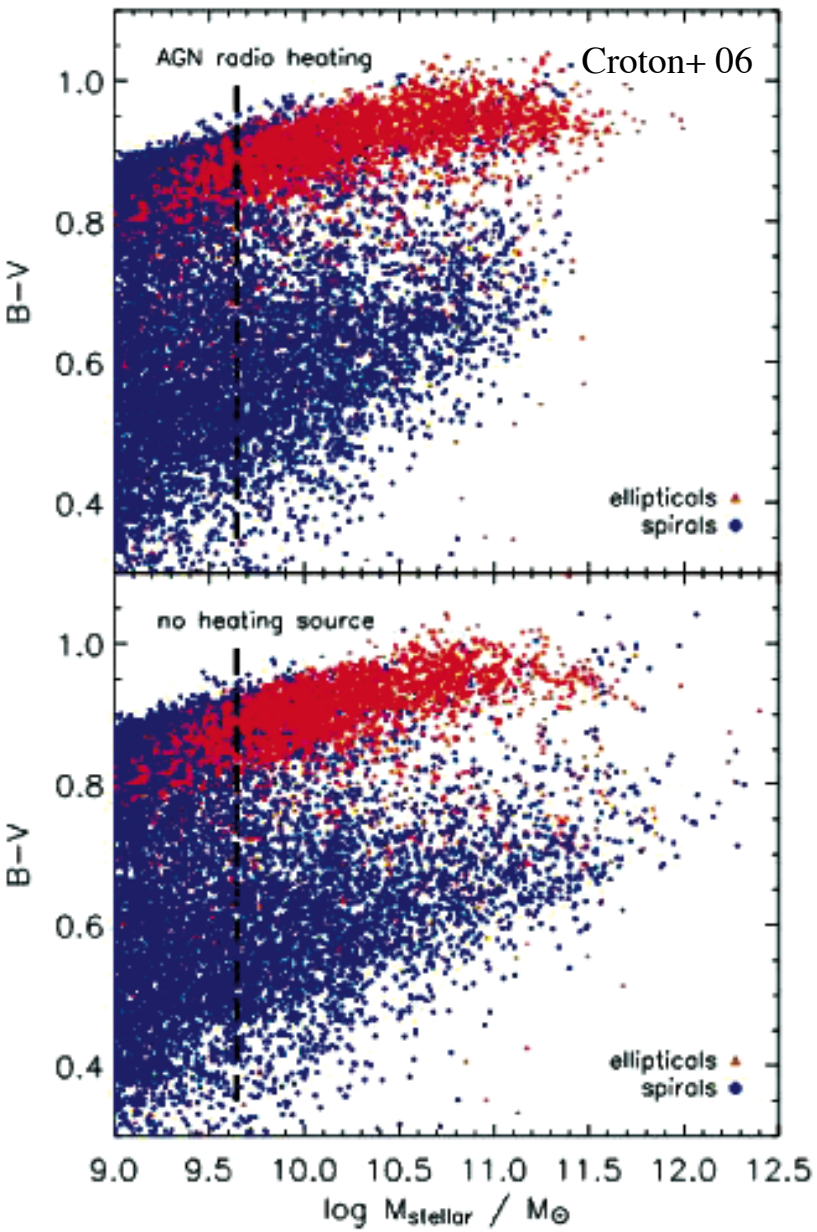


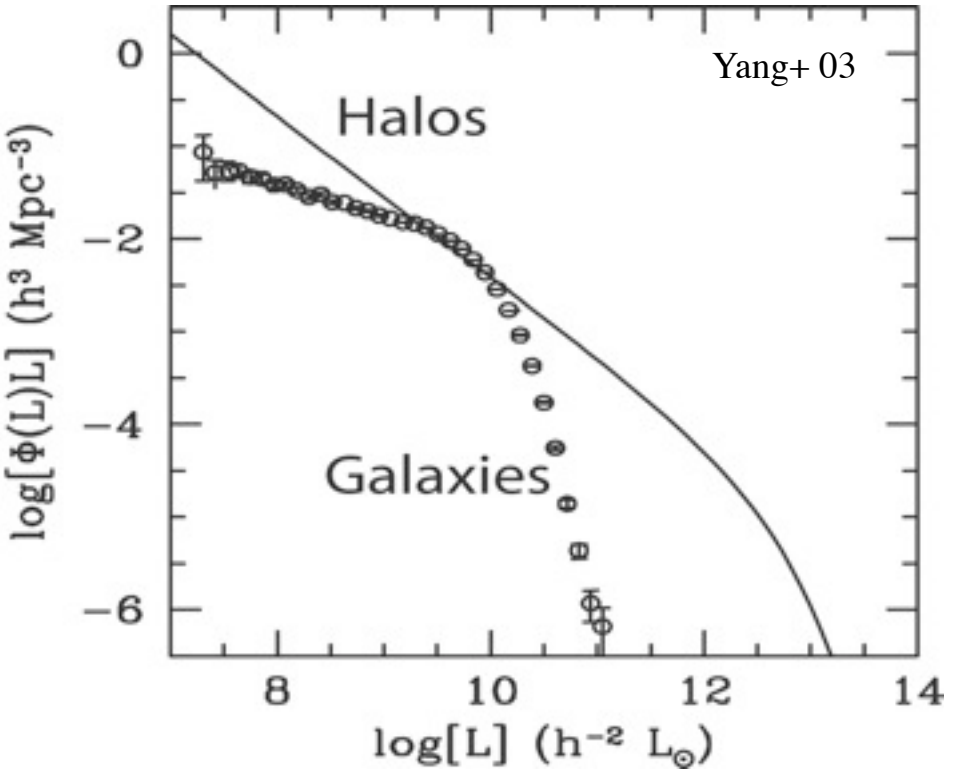
Lars Hernquist, TJ Cox, Dusan Keres, Volker Springel,

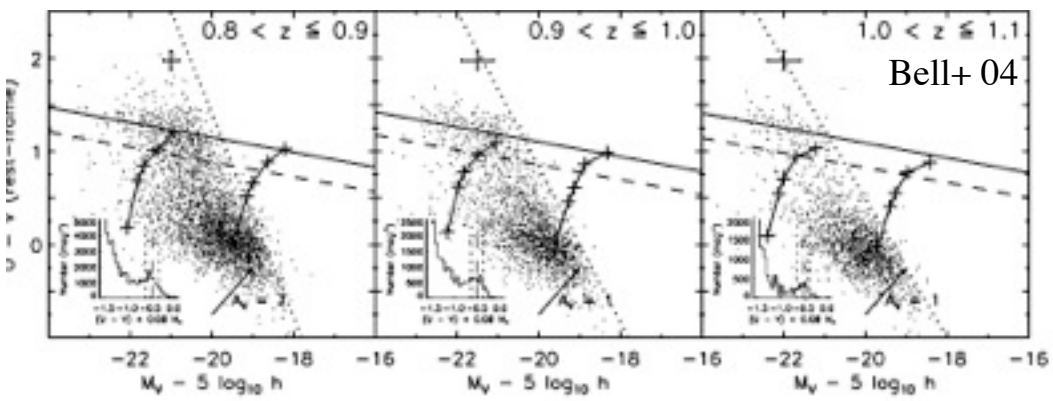
Rachel Somerville (MPIA), Gordon Richards (JHU), Kevin Bundy (Caltech),
Alison Coil (Arizona), Adam Lidz (CfA), Adam Myers (Illinois), Yuexing Li (CfA),
Paul Martini (OSU), Ramesh Narayan (CfA), Elisabeth Krause (Bonn)

Motivation

"QUENCHING" HALTS GROWTH & FORMS RED SEQUENCE



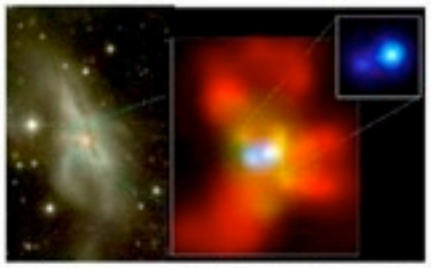




(c) Interaction/"Merger"

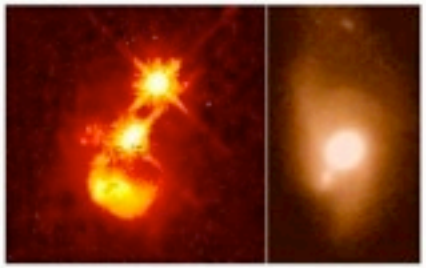
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



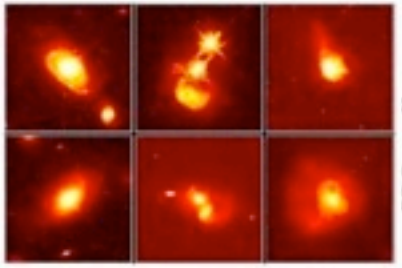
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO:
  - recent/ongoing SF in host
  - high Eddington ratios
  - merger signatures still visible

(f) Quasar

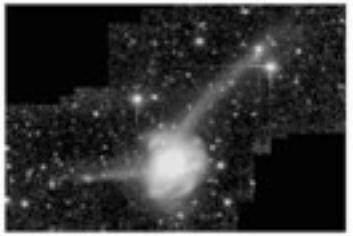


- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

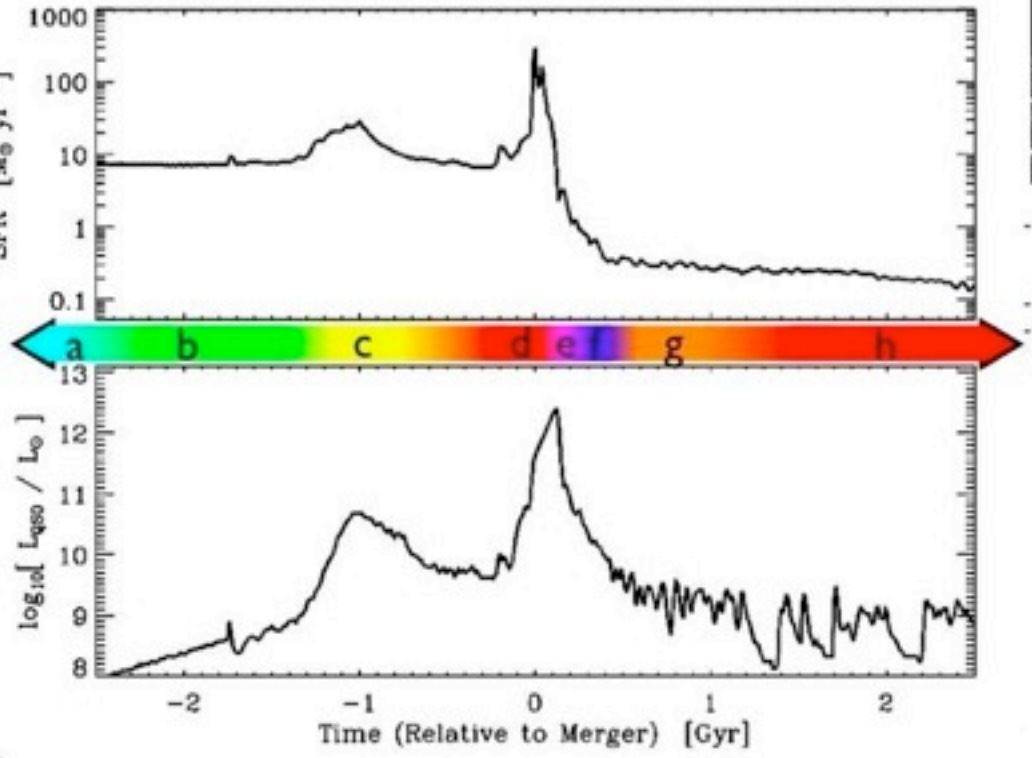
(b) "Small Group"

- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

(g) Decay/K+A



- QSO luminosity fades rapidly
  - tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
  - sets up quasi-static cooling



(a) Isolated Disk

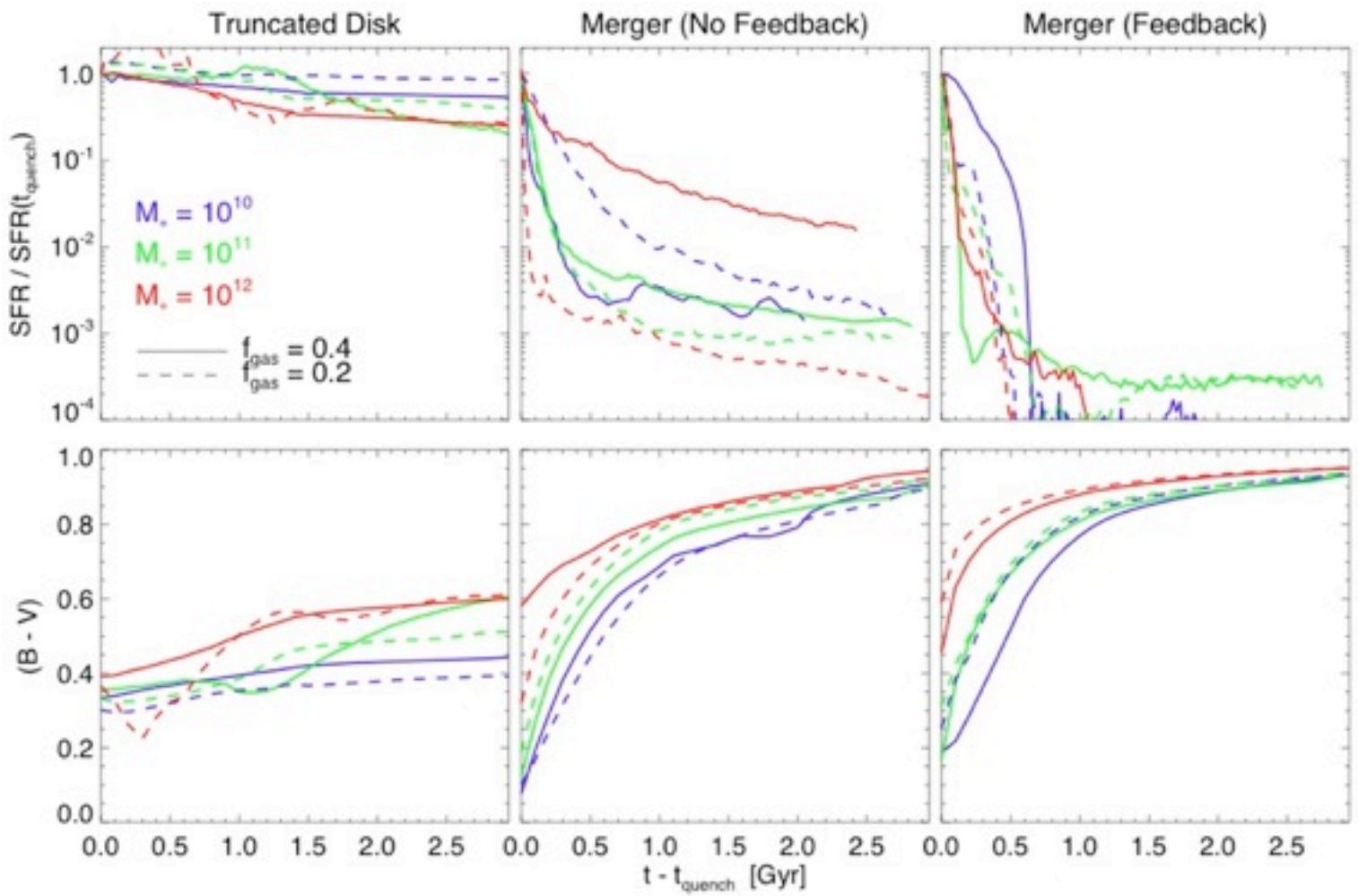
- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with M_B>-23)
- cannot redden to the red sequence

(h) "Dead" Elliptical

- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

Motivation

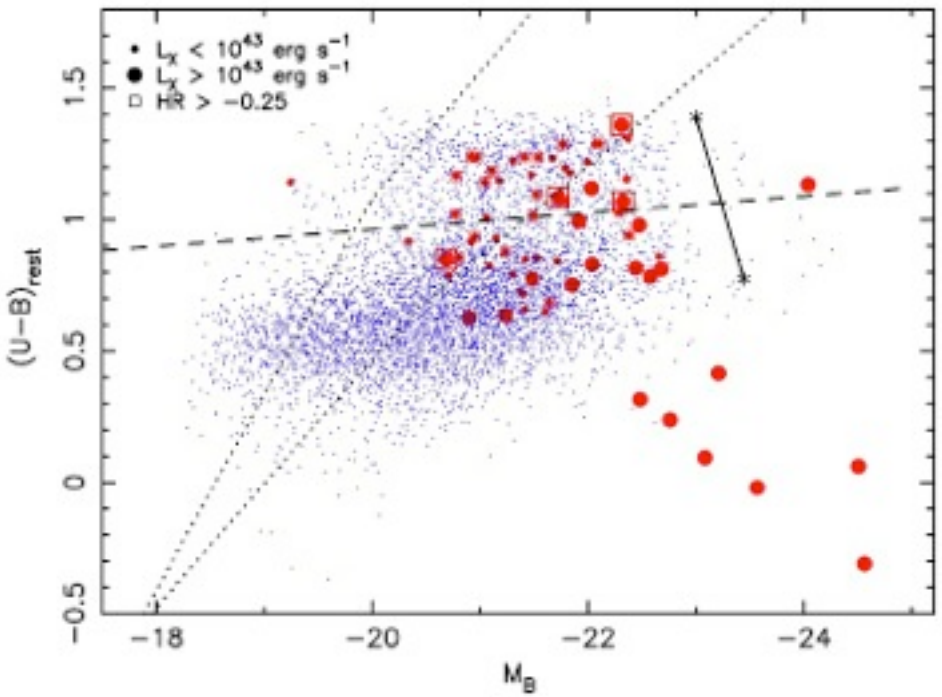
MERGERS AND THE BLUE-RED TRANSITION



- Joanna Woo: Disks aren't "turned off" (red = bulge)?
- Drory & Fisher: Passive/Red = *classical* bulge

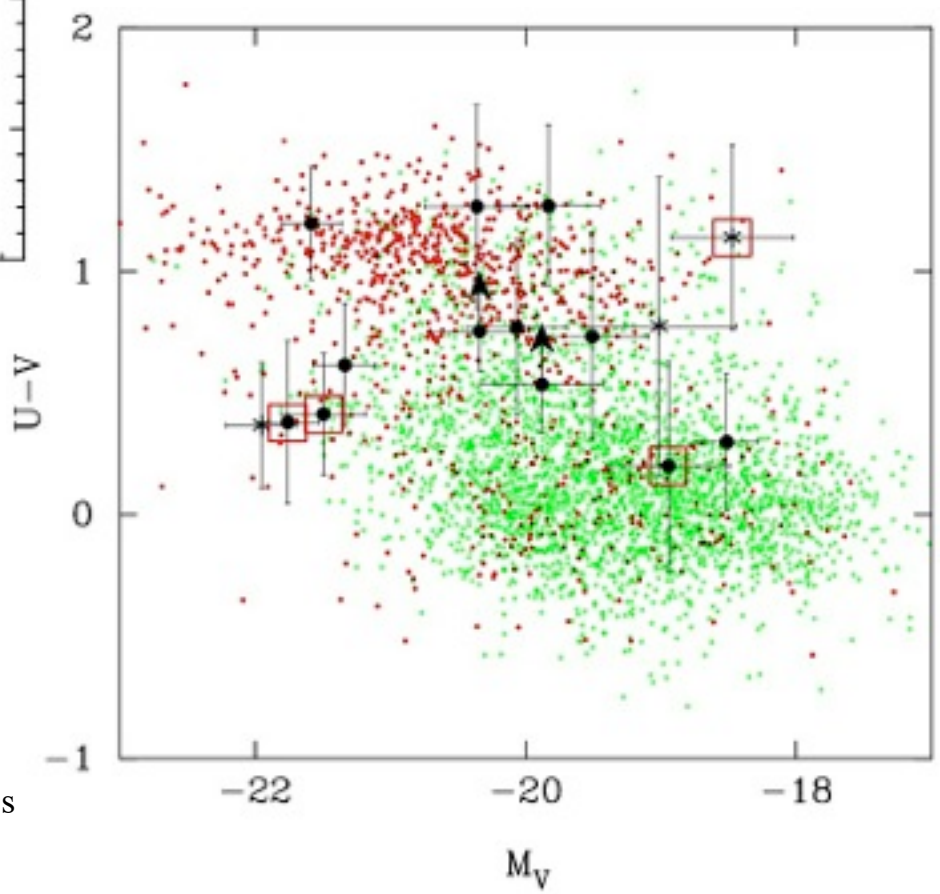
Motivation

CIRCUMSTANTIAL EVIDENCE



Nandra+ ‘06
DEEP2
0.7 < z < 1.4
X-ray QSOs

(also, Kauffmann+ 03;
local SDSS hosts)

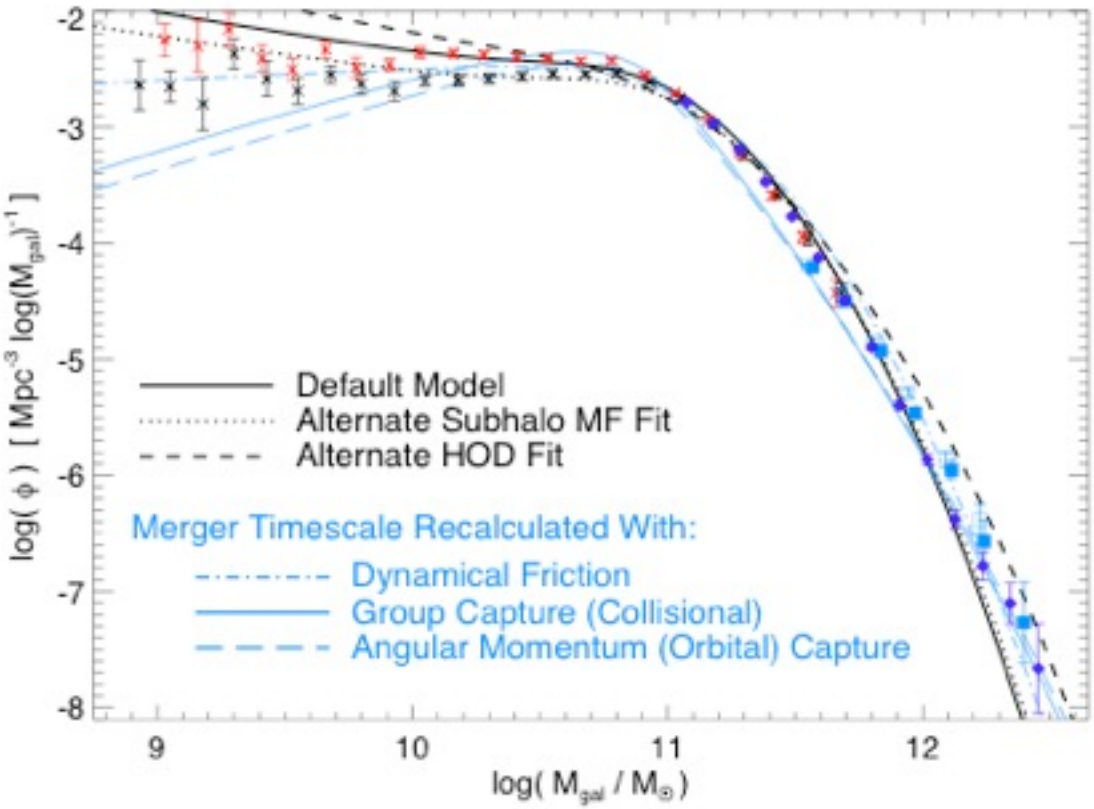


Sanchez+ ‘05
GEMS
0.5 < z < 1.1
Optical QSOs

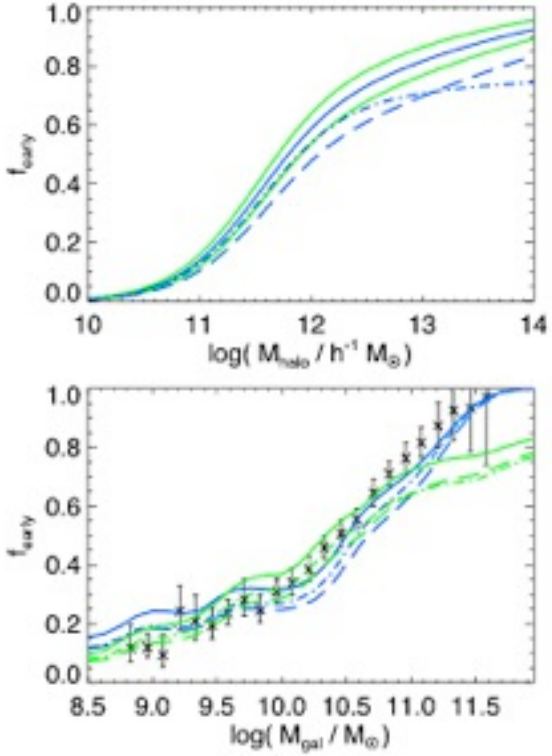
The Model

PREDICTIONS

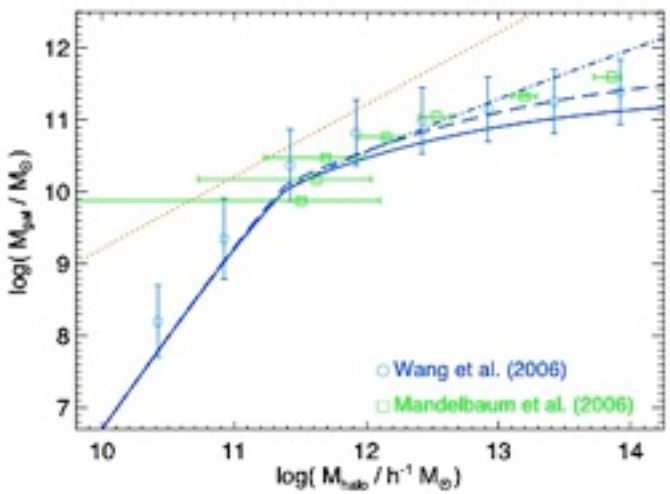
- z=0 mass functions



- red fractions:



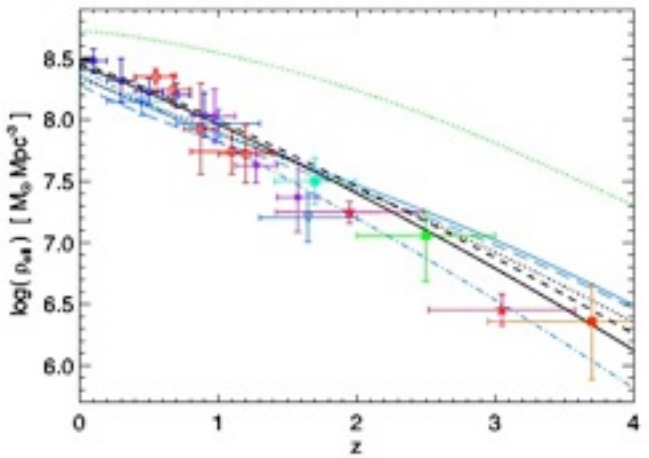
- M/L vs. M_halo



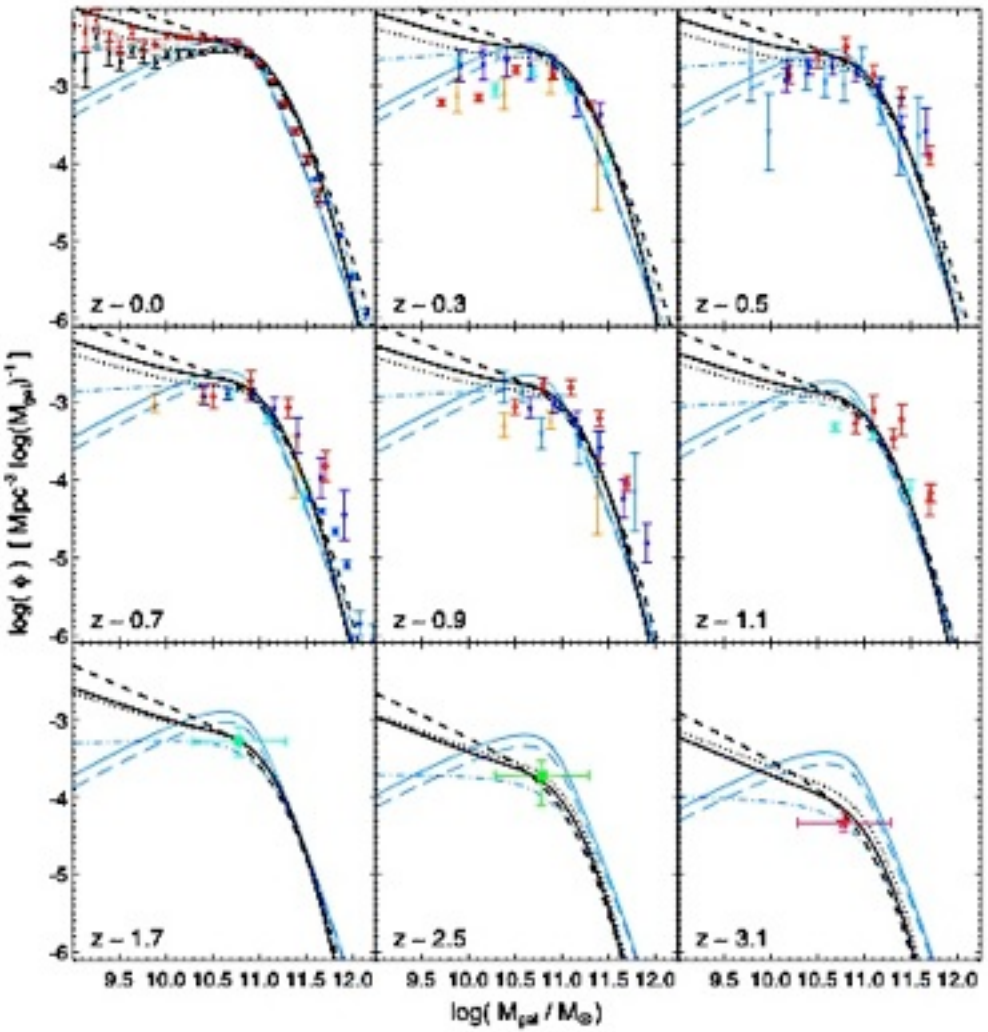
The Model

PREDICTIONS

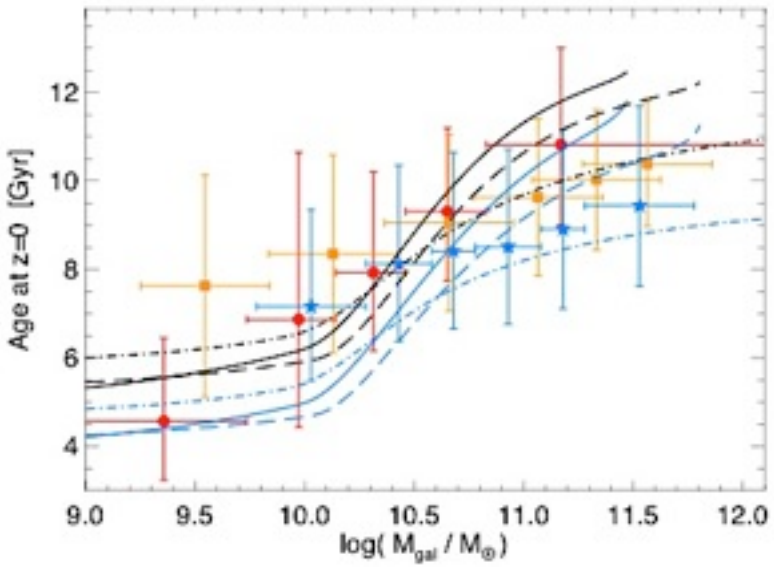
- mass density:



- mass function redshift evolution:



- age vs. mass:



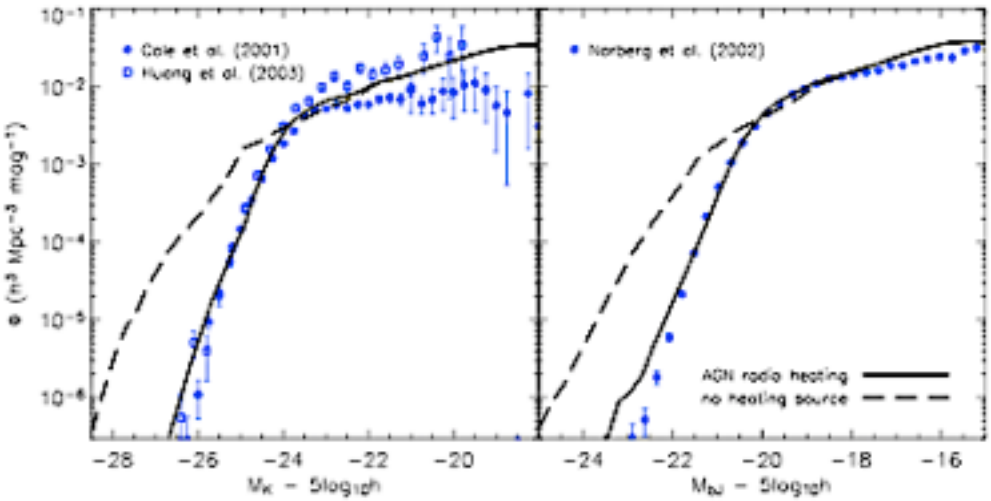
Great!

....BUT....

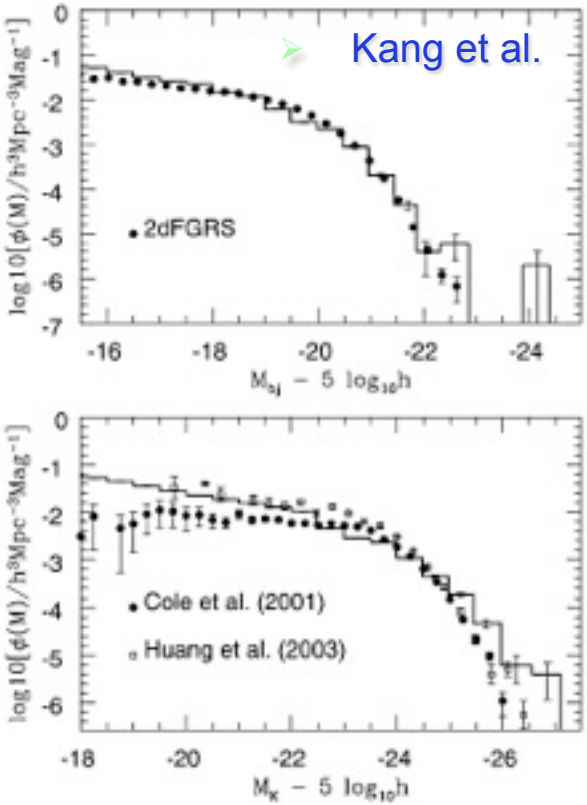
Great!

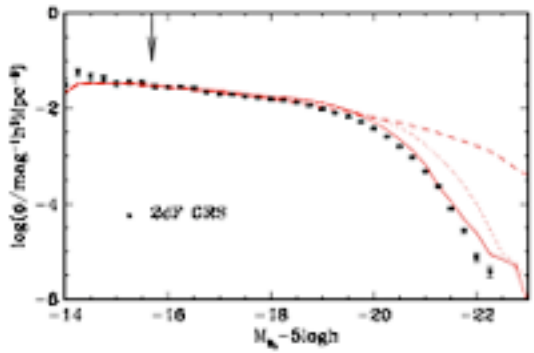
....BUT....

Croton et al.

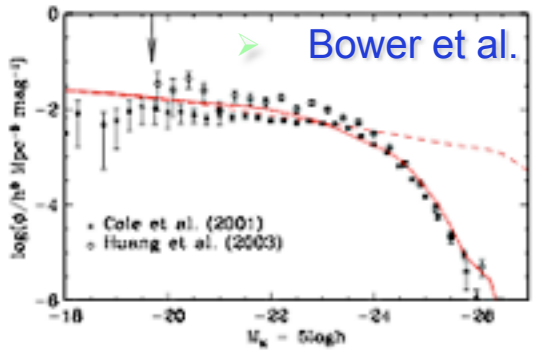


Kang et al.

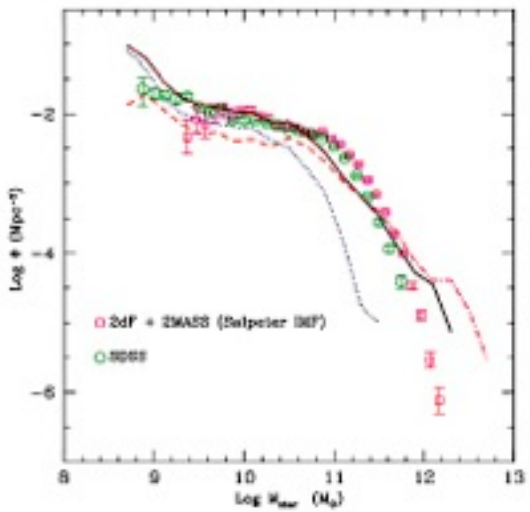




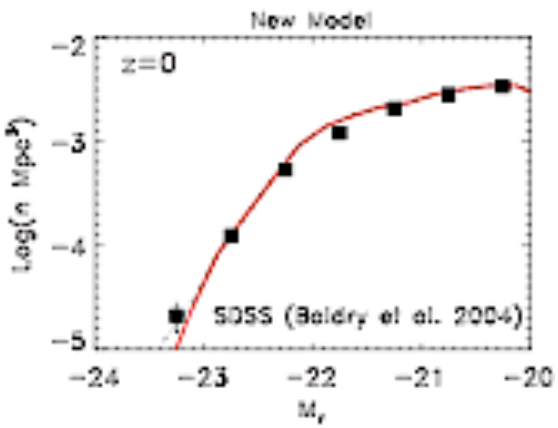
Bower et al.



Monaco et al.



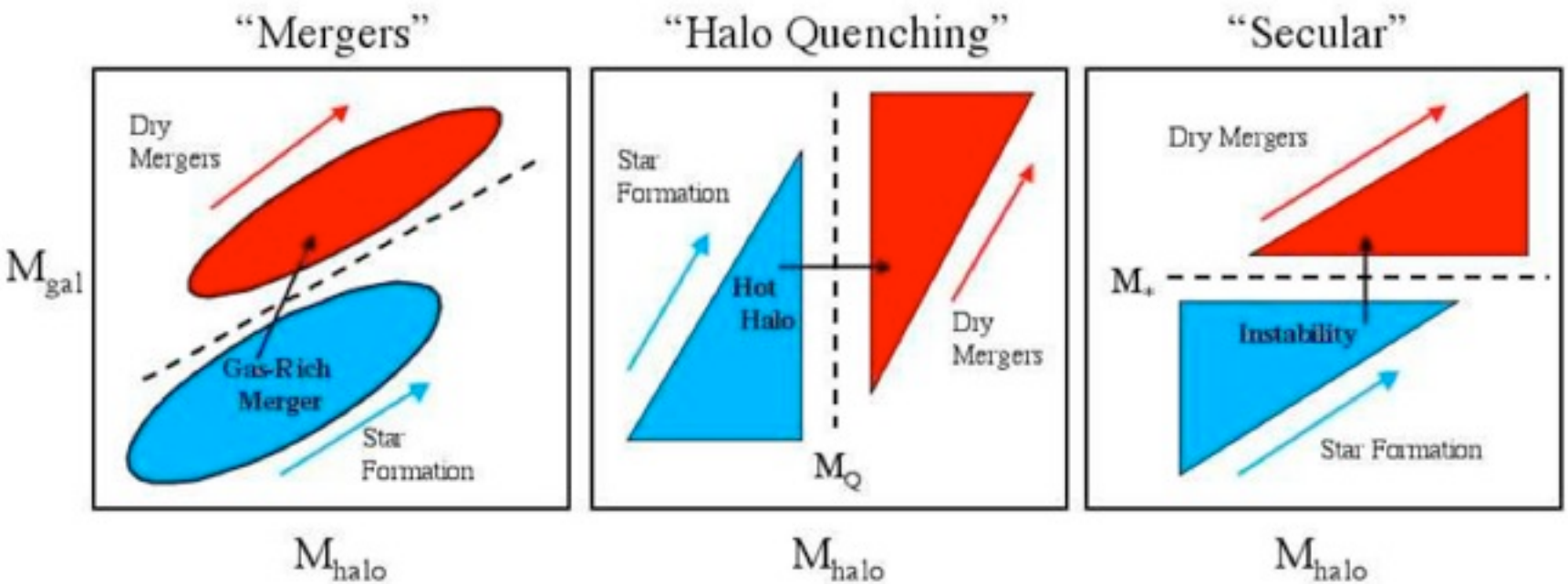
Cattaneo et al.



Lowest-Order Predictions are Fundamentally Non-Unique:

HOW DO WE BREAK THE DEGENERACIES?

- Identify broad classes of quenching models:

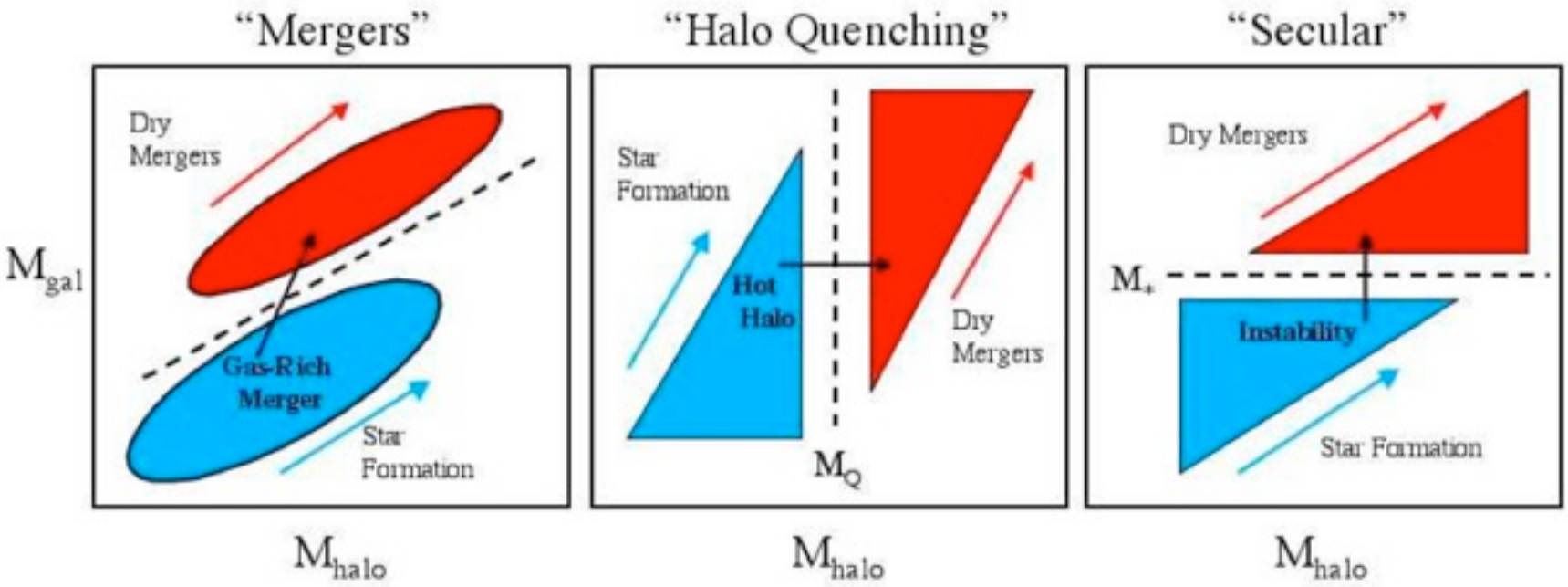


- Are there unique, robust predictions of the different classes of quenching mechanisms?

Lowest-Order Predictions are Fundamentally Non-Unique:

HOW DO WE BREAK THE DEGENERACIES?

- Identify broad classes of quenching models:



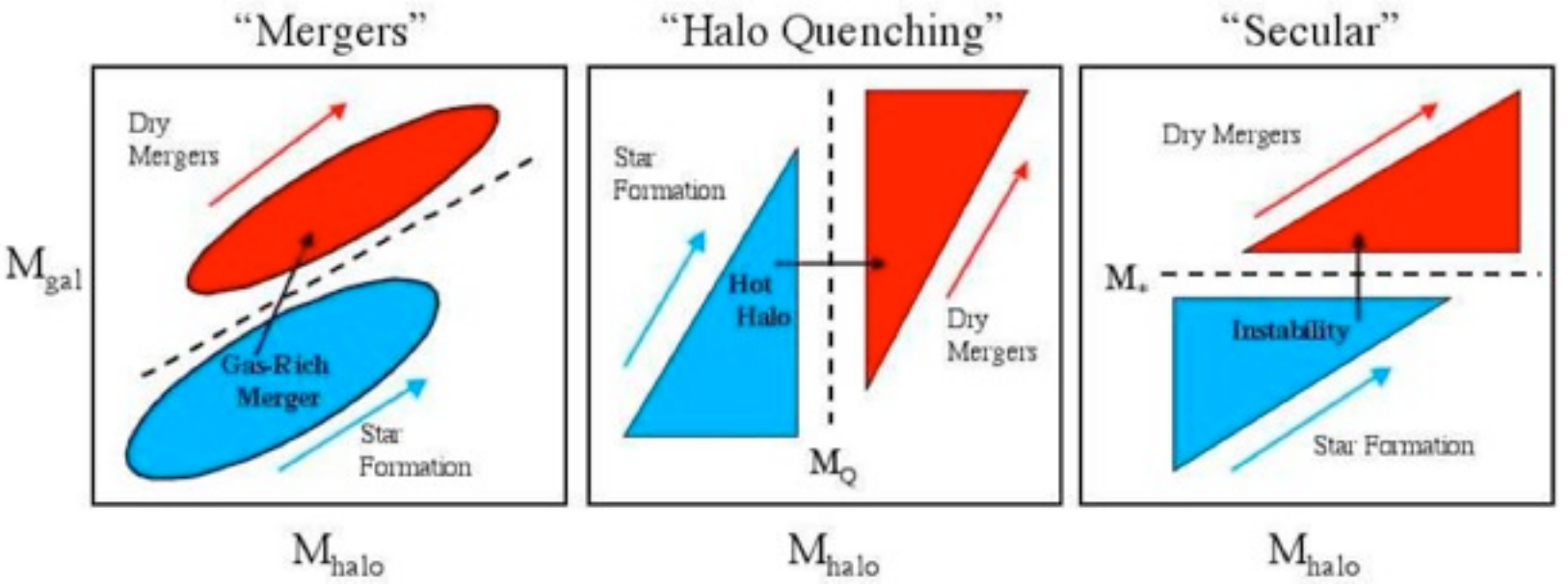
Khochfar & Silk (w. Naab et al.)
Cattaneo et al. (alt)
Somerville et al. (new)
Hopkins et al. (too many)

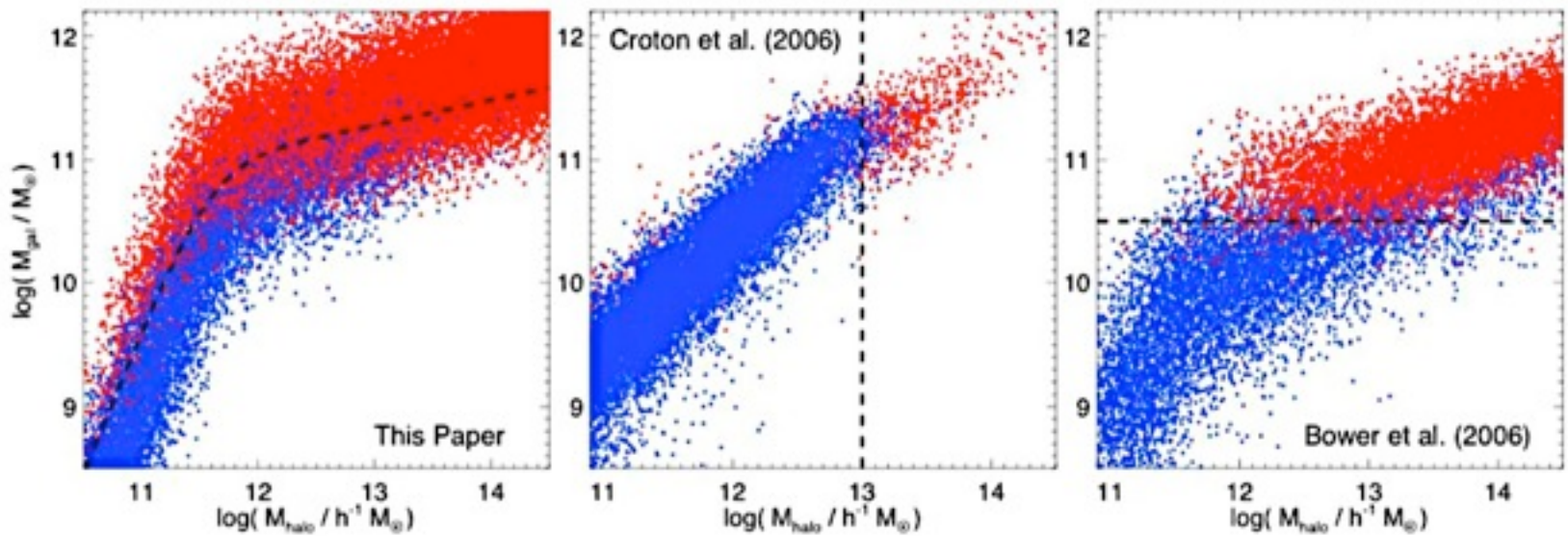
Croton et al.
De Lucia et al.
Bower et al.
Cattaneo et al. (standard)
Kang et al.
Monaco et al. (no QSO)

Bower et al. (sometimes)
Noeske et al.

Comparing Quenching Models

HOW DO WE BREAK THE DEGENERACIES?





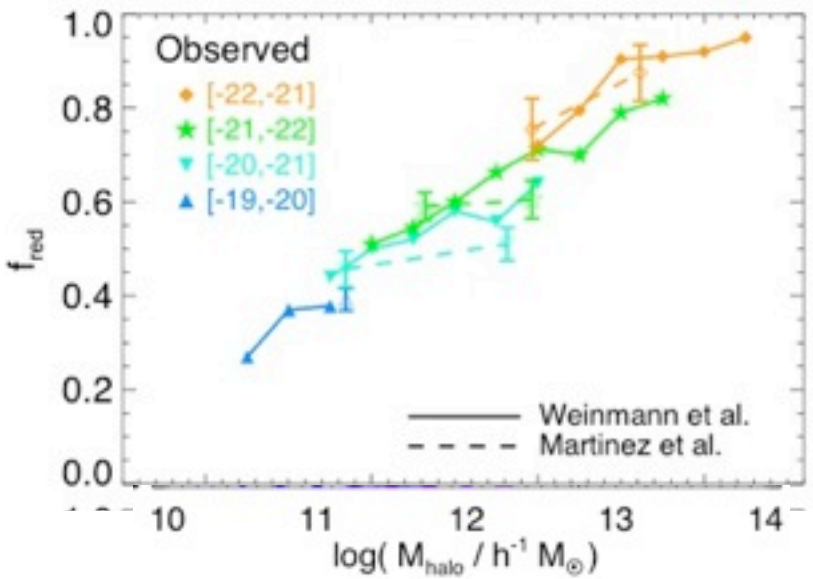
Motivation

WHAT DO WE KNOW?

	Mergers	Hot Halos	Secular
morphology:	classical bulges/ spheroids	little effect	"pseudobulges"
BH/AGN:	*quasar & remnant massive BH	*little BH growth *fuel for low Mdot modes?	*Seyferts? *small (<10^7 M_sun) BHs
feedback:	*kinematic *quasar *starburst	*accretion shocks *gravitational	*Seyfert? *stellar winds
timescales:	short (<Gyr)	~Hubble time	~Gyr?

Comparing Quenching Models

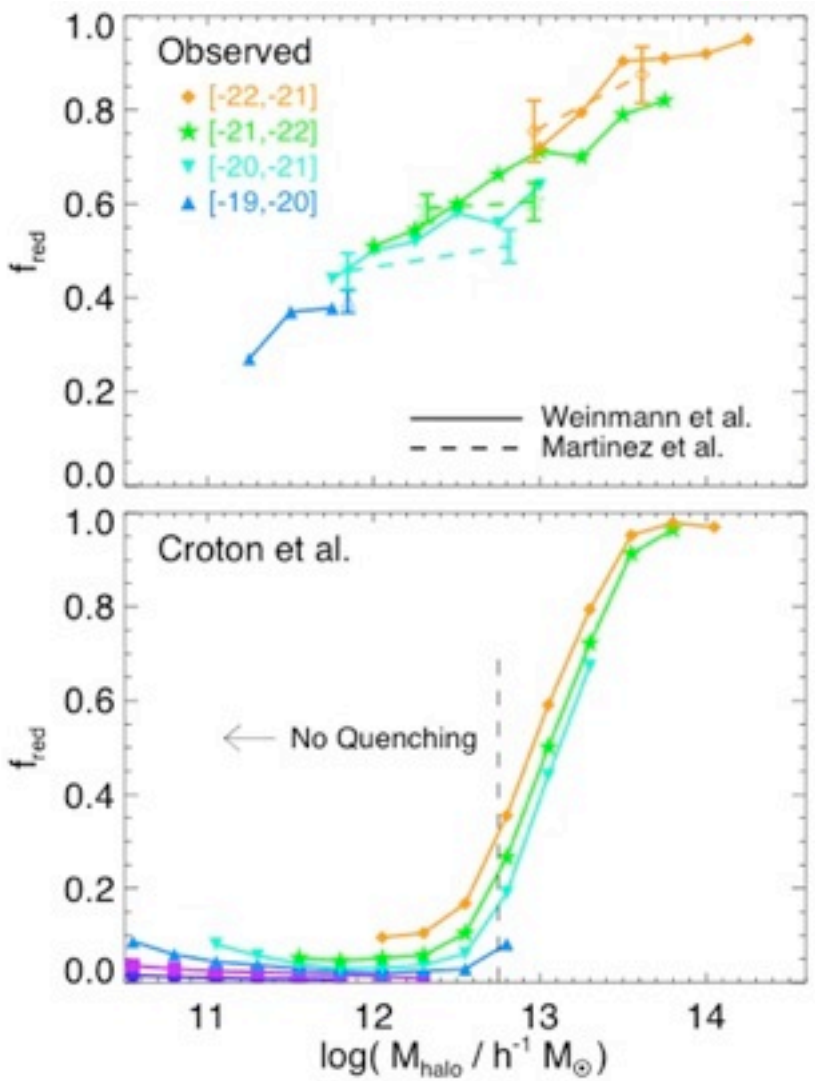
HOW DO WE BREAK THE DEGENERACIES?



- f_red vs. M_halo and M_gal:
  - smooth dependence on M_halo
  - no characteristic scale
  - high even in low M_halo (for massive galaxies)

Comparing Quenching Models

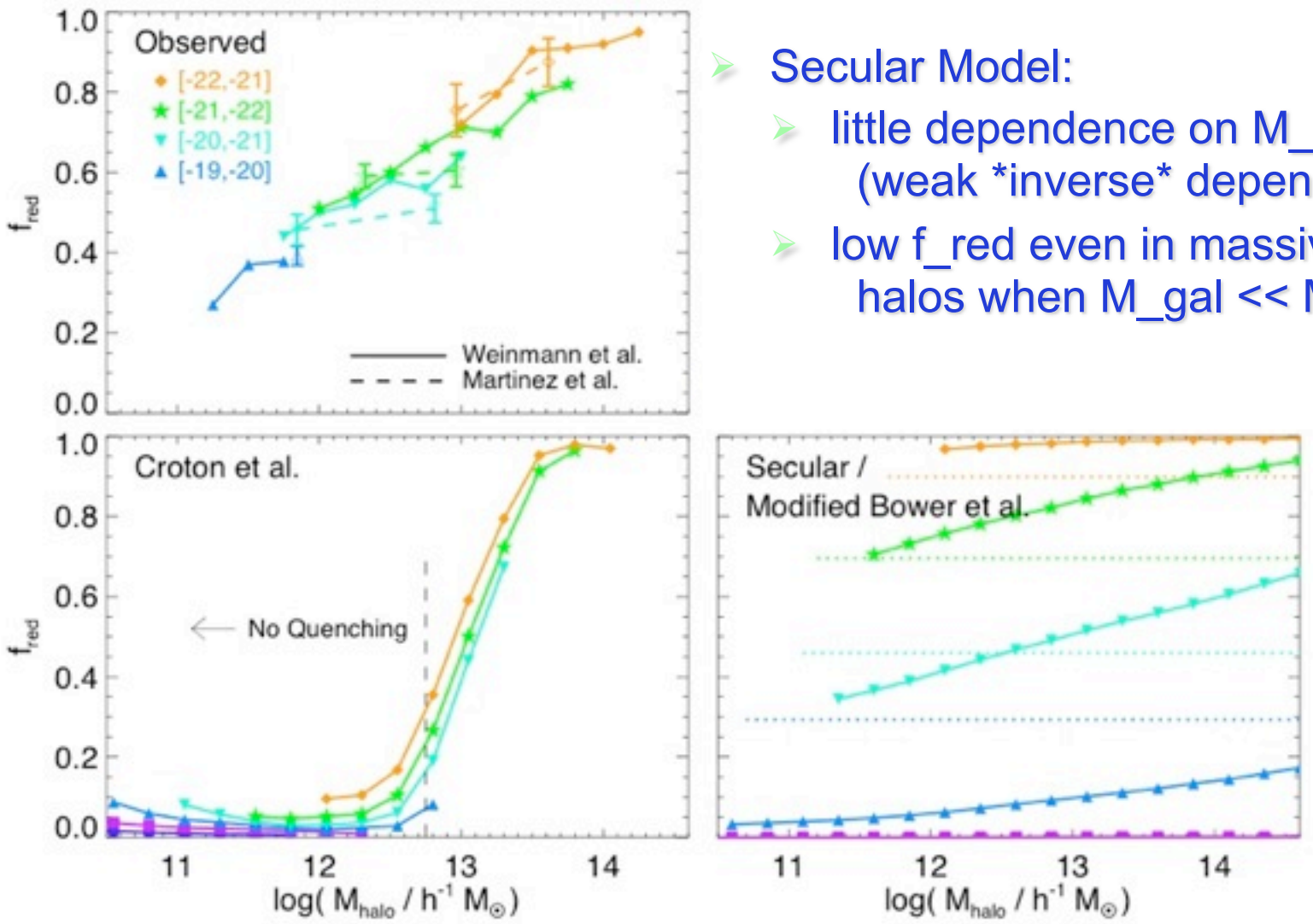
HOW DO WE BREAK THE DEGENERACIES?



- "Halo Quenching" Model:
  - step function in M_halo: strong characteristic scale
  - no residual M_gal dependence
  - no f_red in low M_halo

Comparing Quenching Models

HOW DO WE BREAK THE DEGENERACIES?

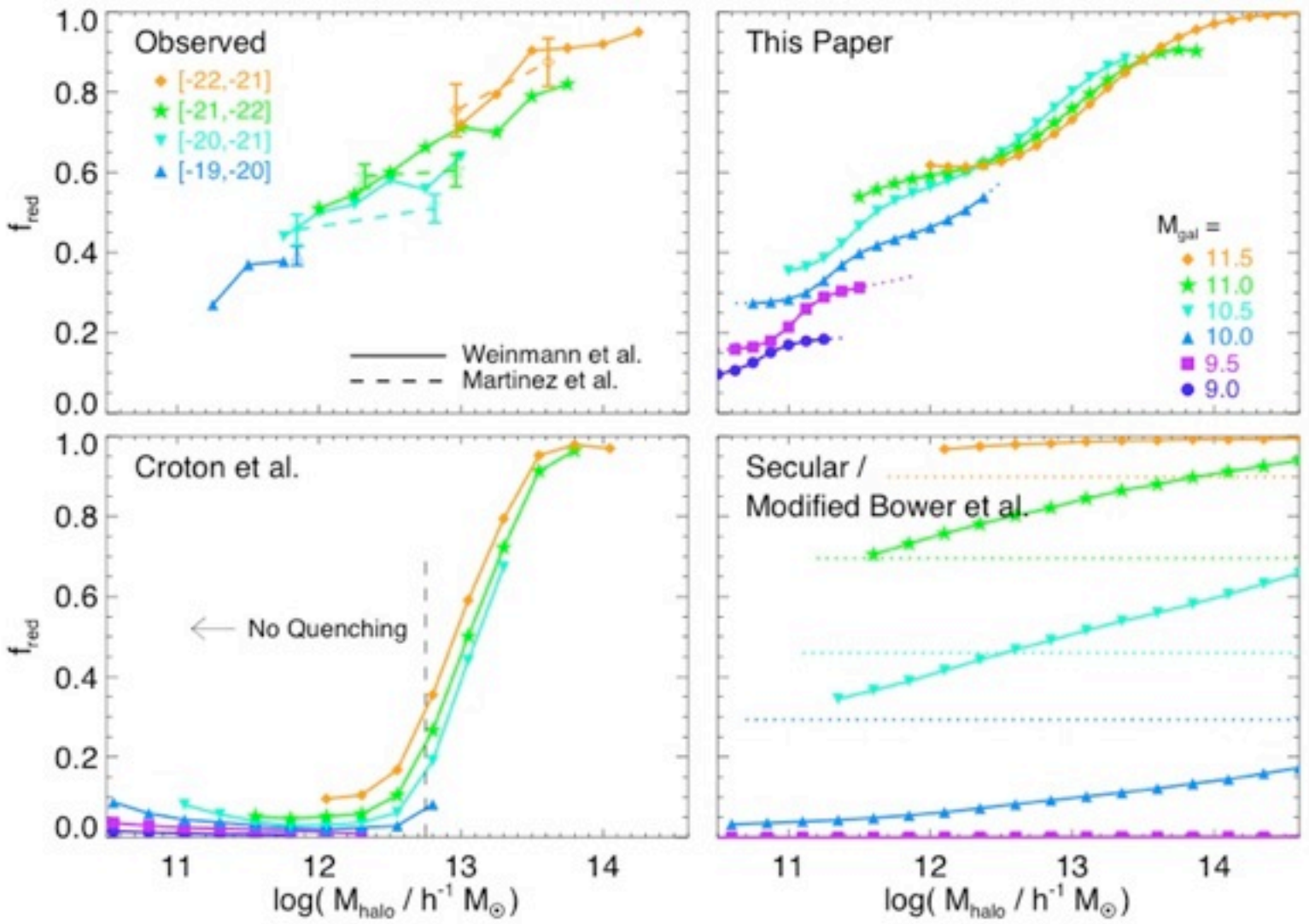


- Secular Model:
  - little dependence on M_halo (weak *inverse* dependence)
  - low f_red even in massive halos when M_gal << M*

Comparing Quenching Models

HOW DO WE BREAK THE DEGENERACIES?

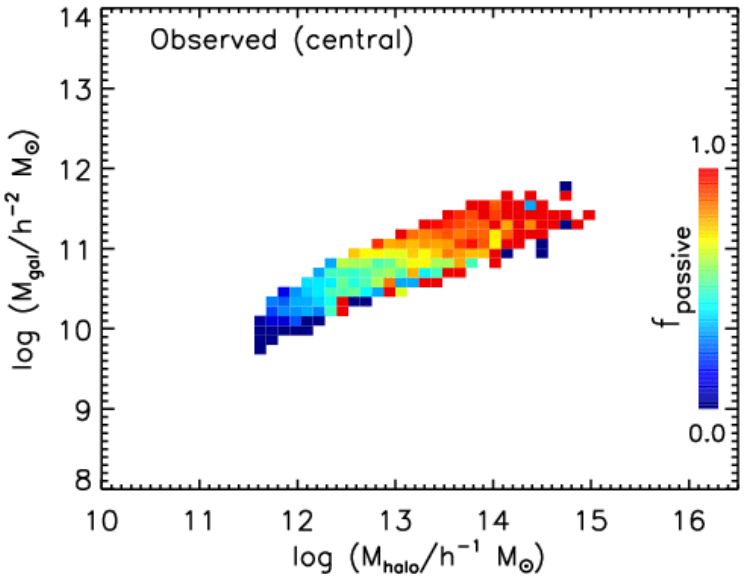
- Merger Model:
  - appropriate mixed dependence on M_halo and M_gal
  - no sharp scale in M_halo

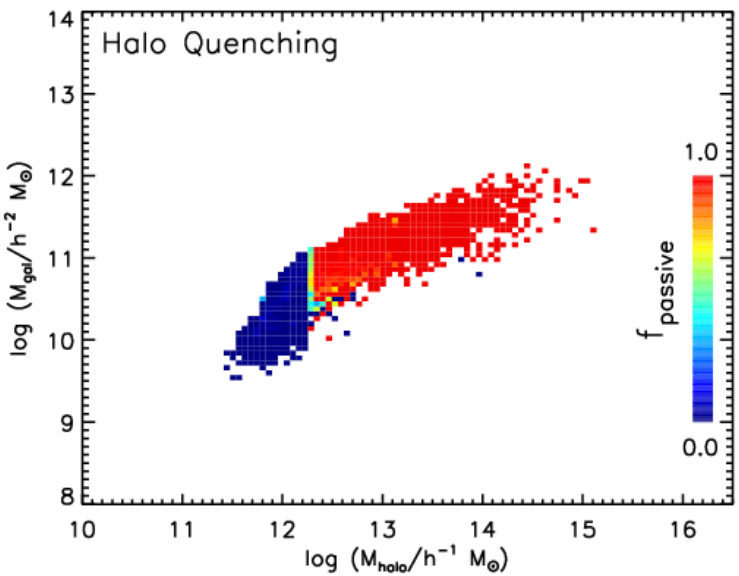


Comparing Quenching Models

HOW DO WE BREAK THE DEGENERACIES?

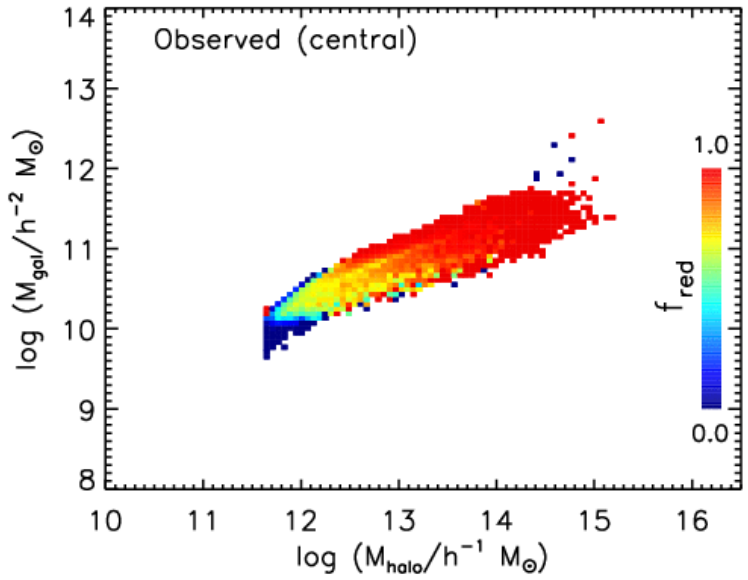
- Passive (low SSFR) galaxies:
  - same trends
  - avoid dusty/metal-rich disk contamination

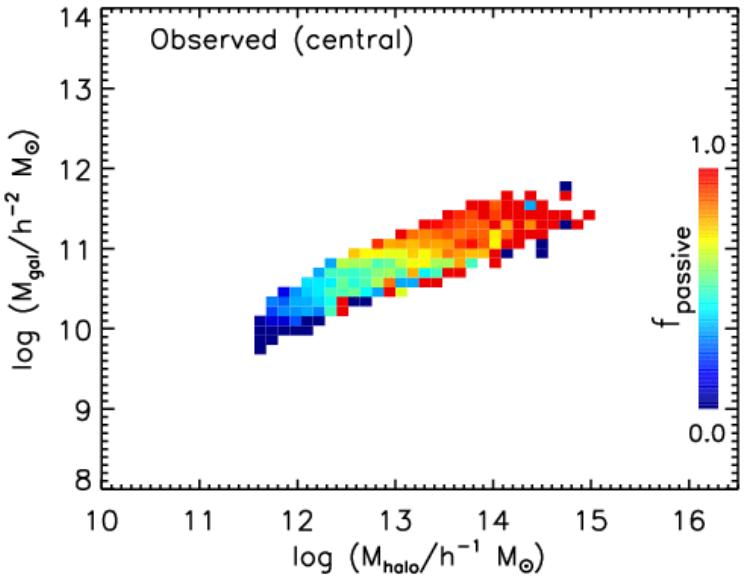


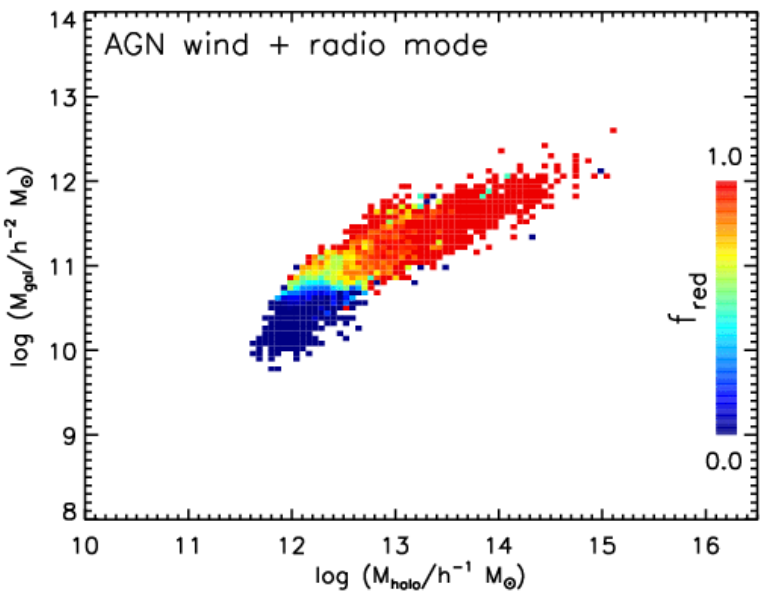


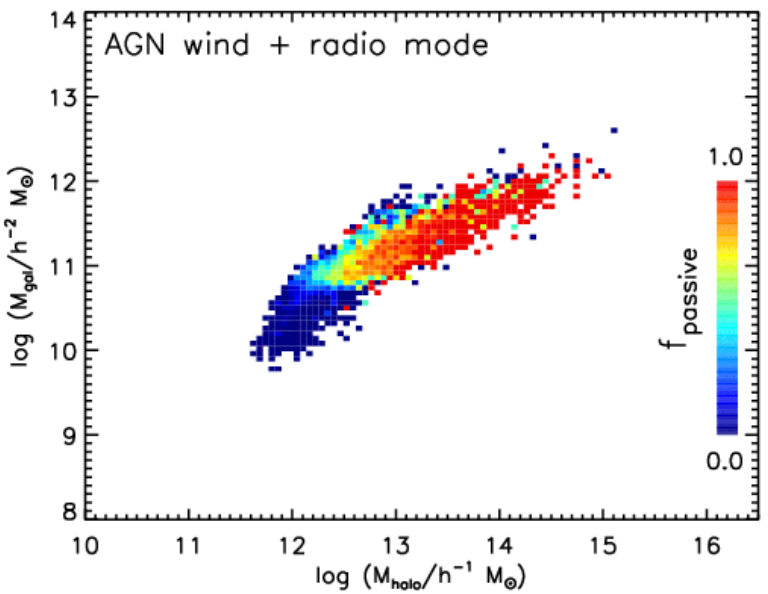
Comparing Quenching Models

HOW DO WE BREAK THE DEGENERACIES?







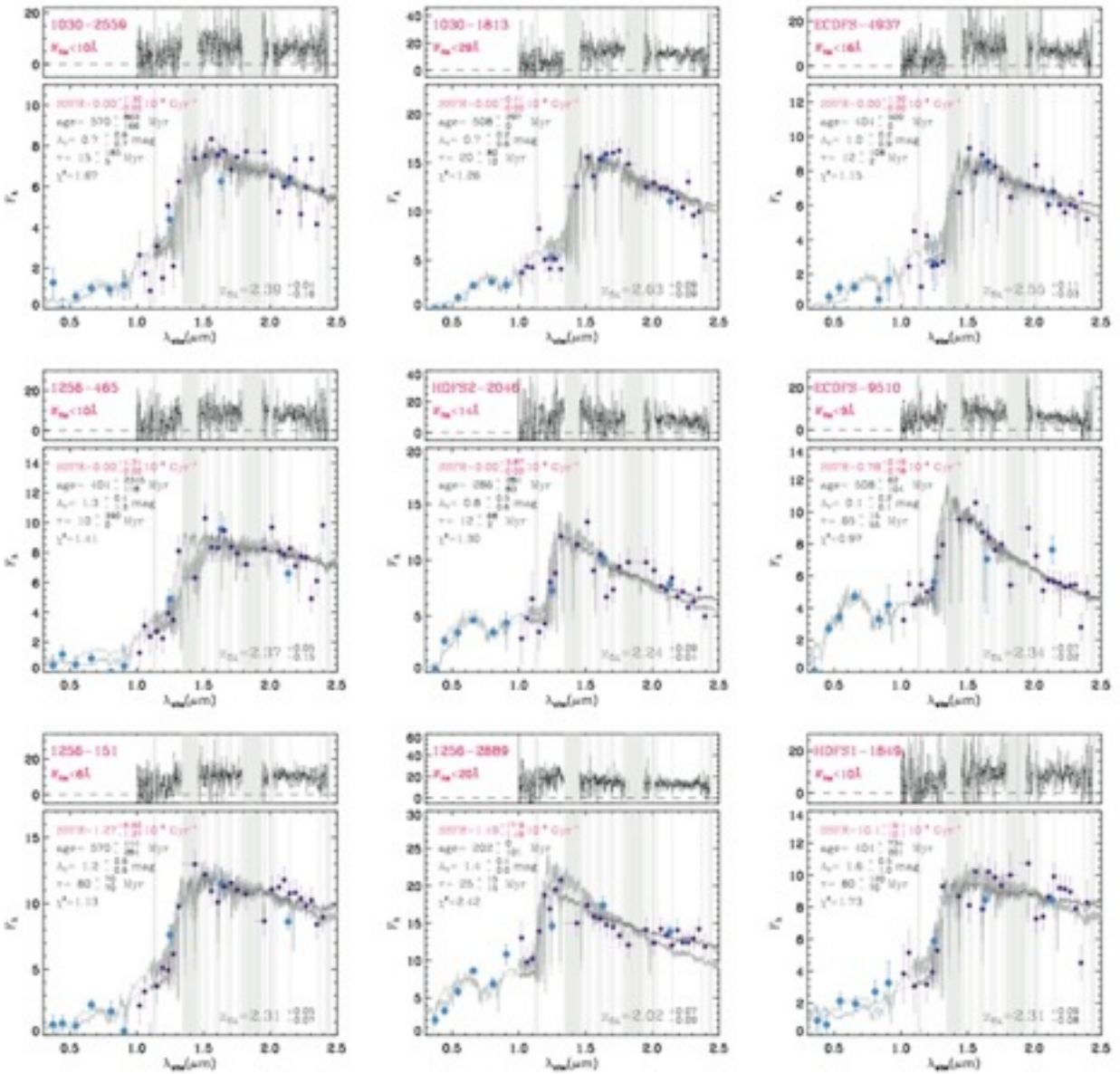


Comparing Quenching Models

HIGH-REDSHIFT PASSIVE GALAXIES

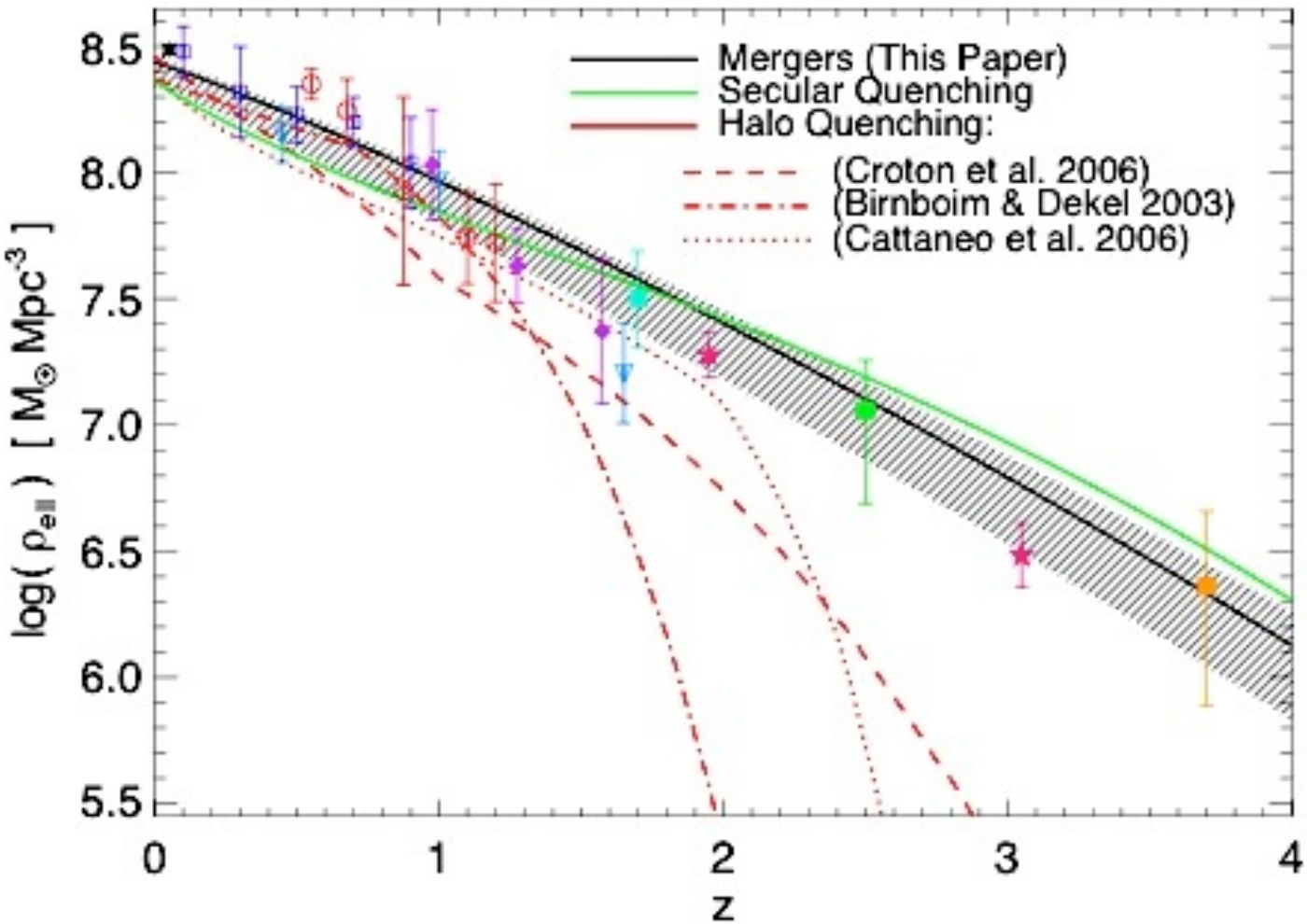
Kriek et al., Labbe et al., Zirm et al.

- High-z passive (low SSFR) galaxies:
  - z ~ 2 - 4
  - Very compact, n~4: Spheroids/Merger remnants
  - High (low-lum) AGN fraction



Comparing Quenching Models

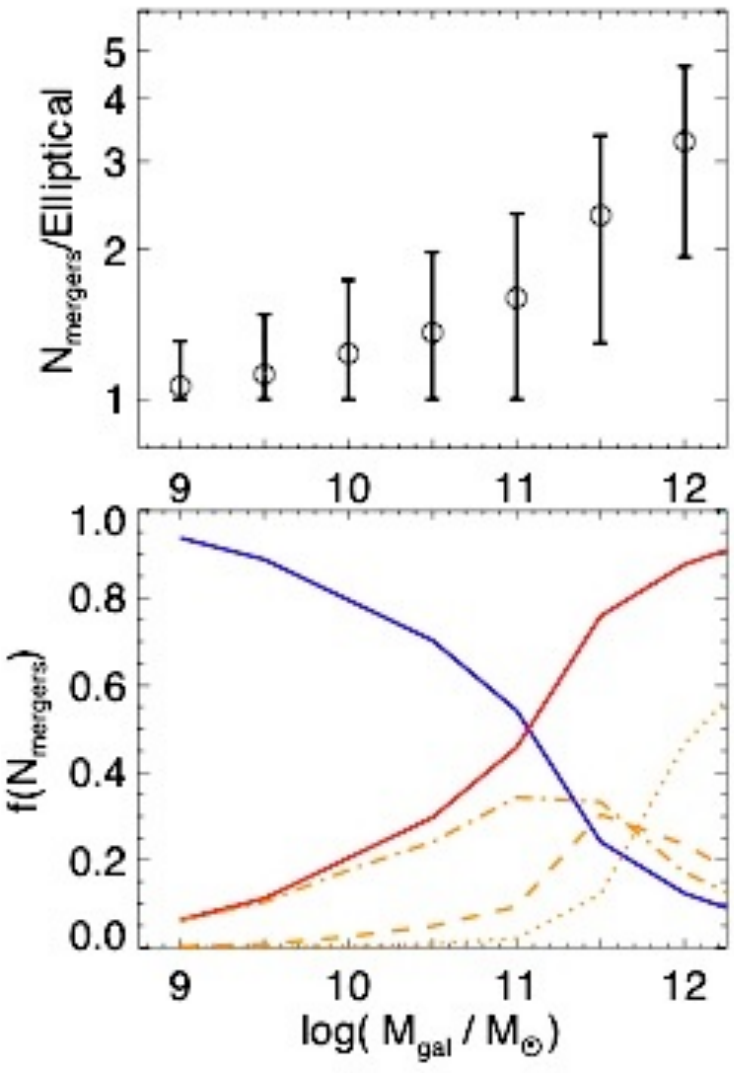
HIGH-REDSHIFT PASSIVE GALAXIES

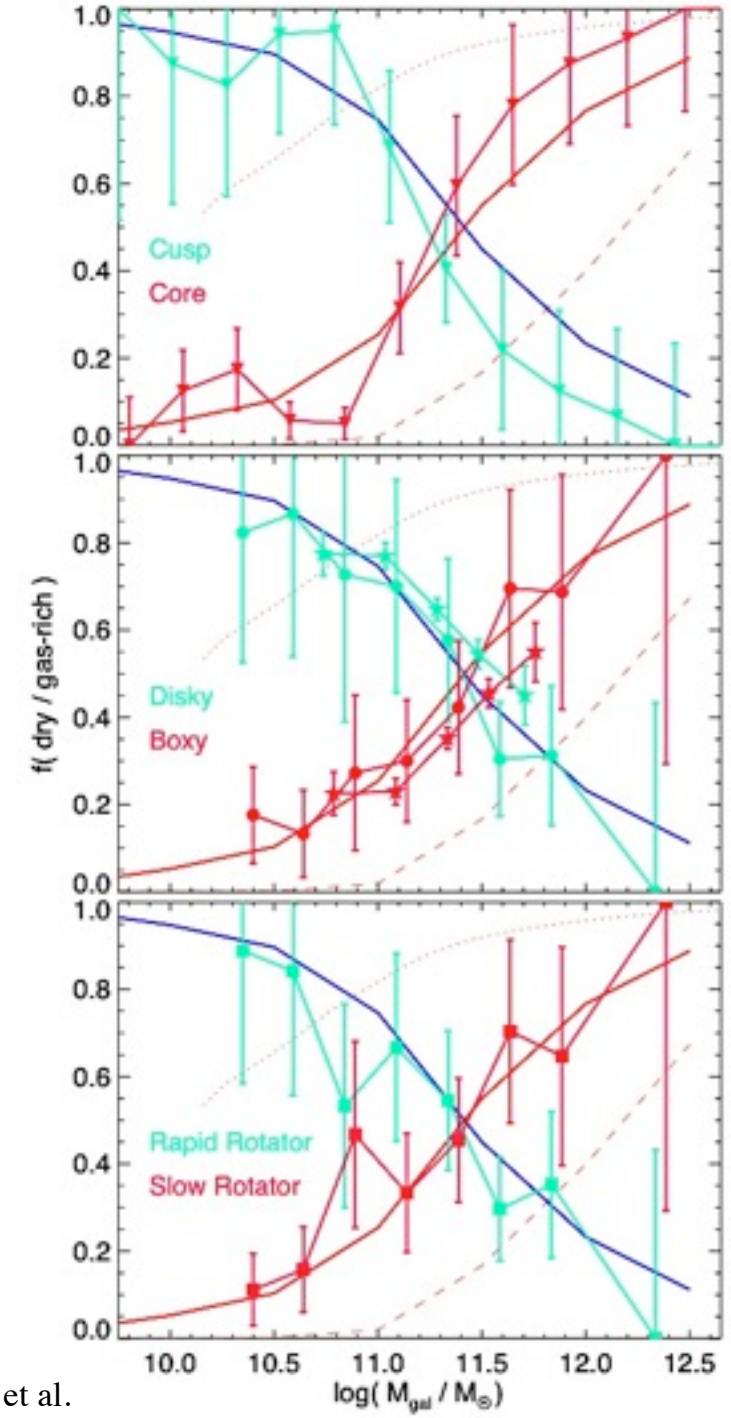


Kriek et al., Daddi et al.,
Grazian et al., Van Dokkum et al.

Comparing Quenching Models

DICHOTOMY IN ELLIPTICAL KINEMATICS

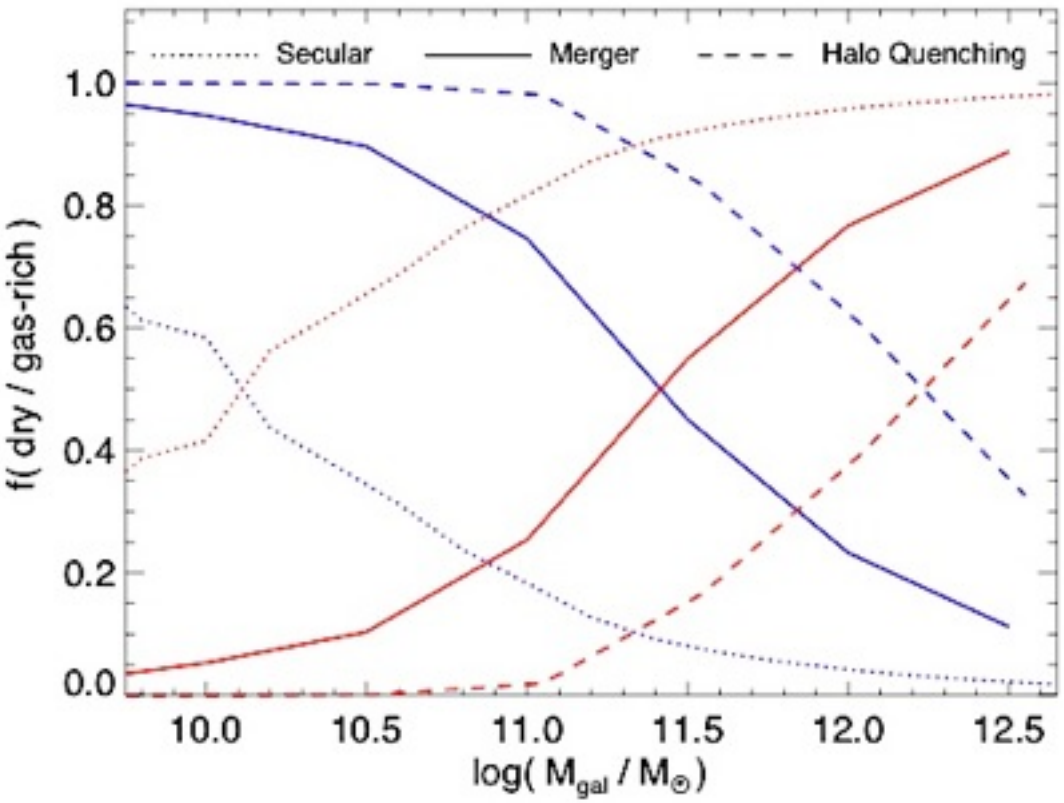


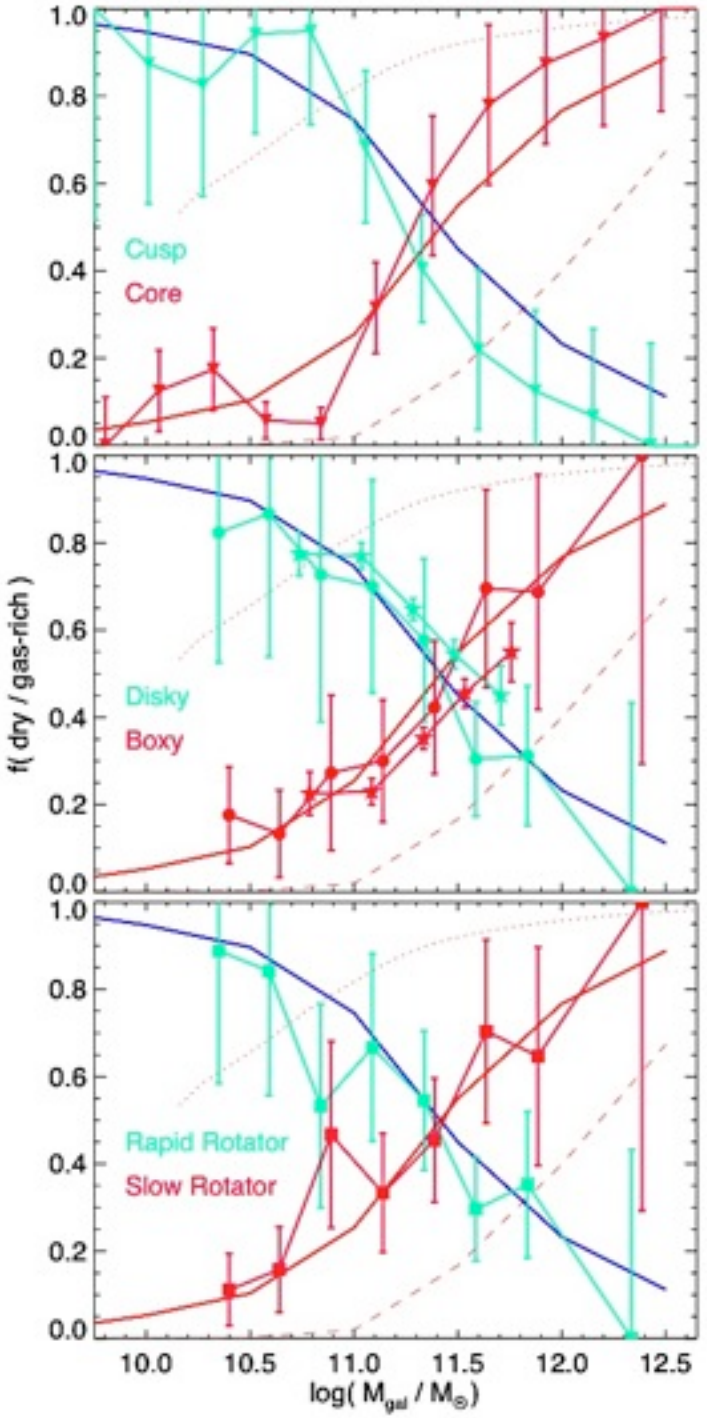


Lauer et al., Bender et al., Pasquali et al.

Comparing Quenching Models

DICHOTOMY IN ELLIPTICAL KINEMATICS

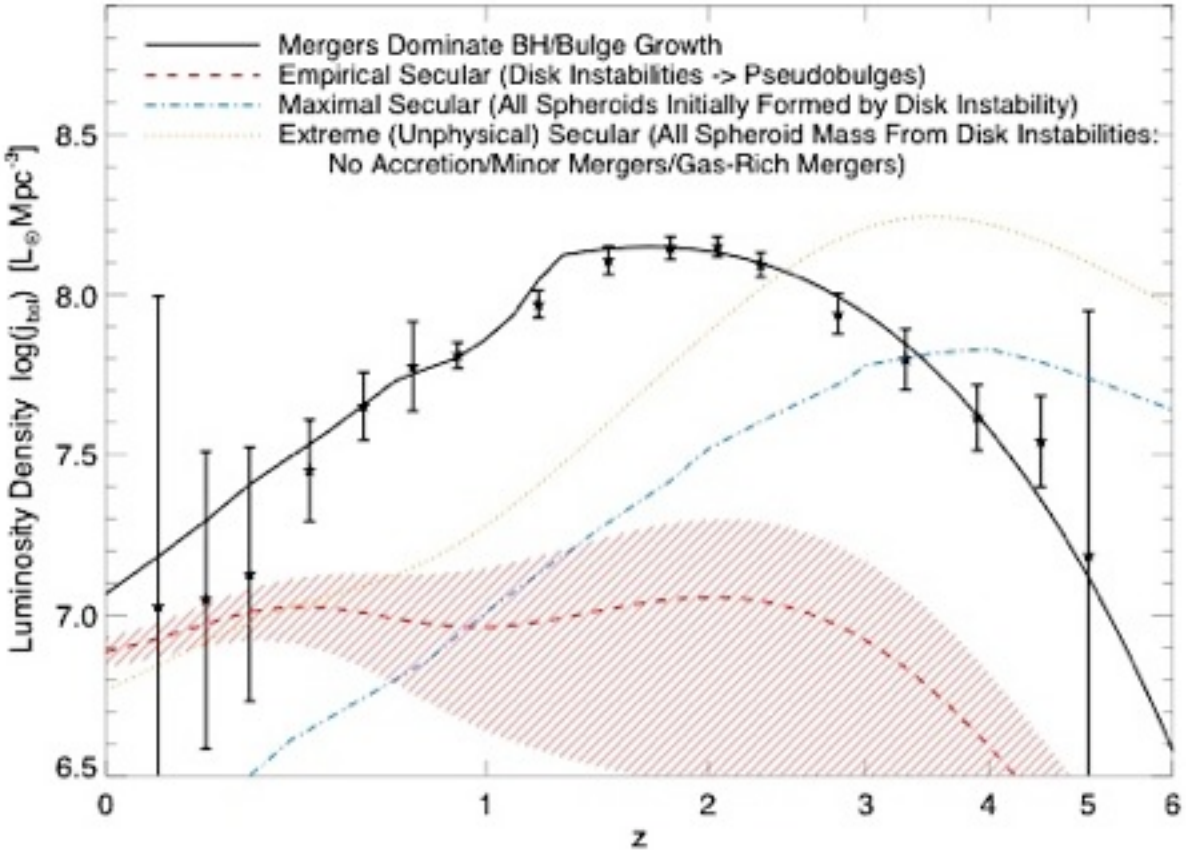


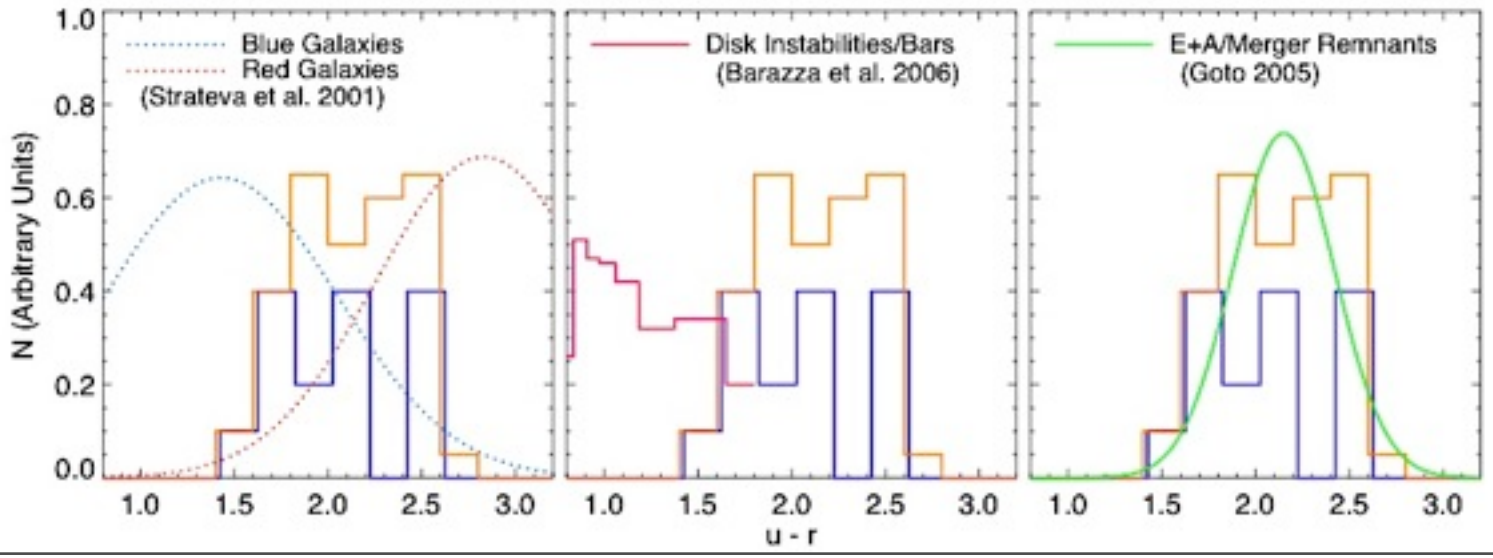


- See also Naab et al., Kang et al., Kochfar & Silk

LF vs. Redshift

UV THROUGH IR





Comparing Quenching Models

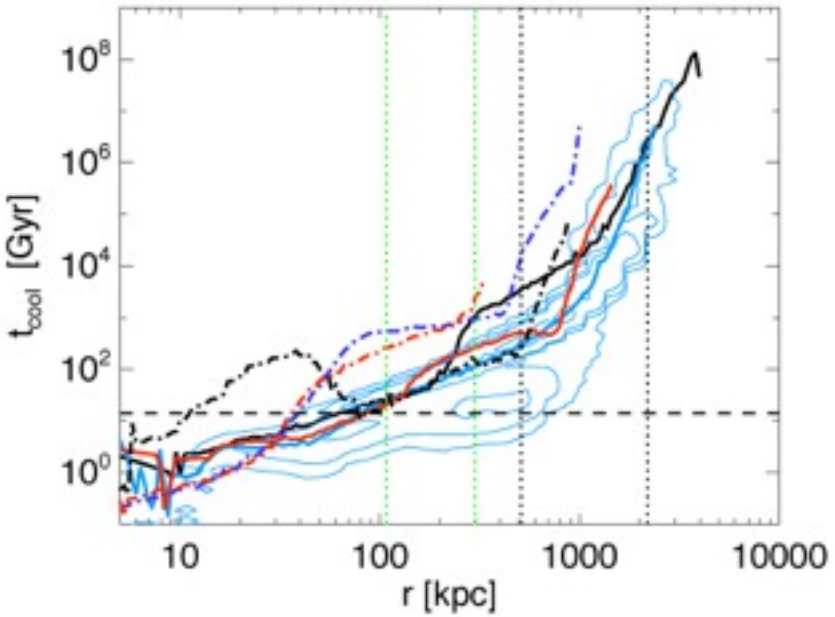
SUMMARY

- Strong arguments for association between mergers, quasars, & blue-red transition:
  - clustering, number densities, merger fractions, morphologies, host colors/SFHs, LF evolution, kinematics, etc.

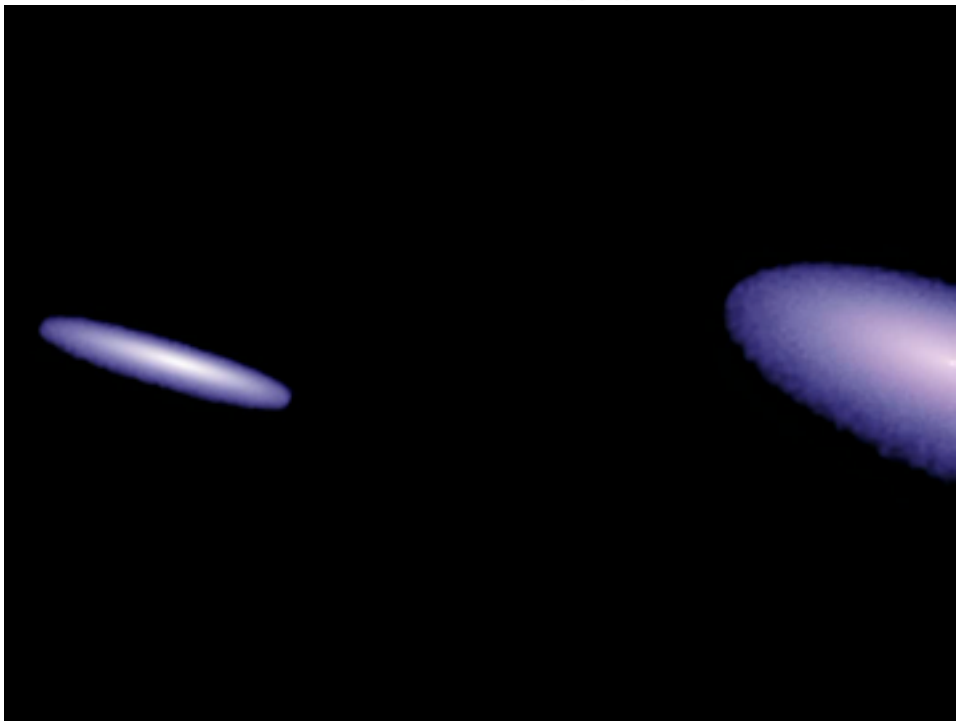
- But, how is quenching over a Hubble time accomplished by a single, potentially high redshift gas-rich major merger?

How Could Mergers Be Associated with “Maintenance”?

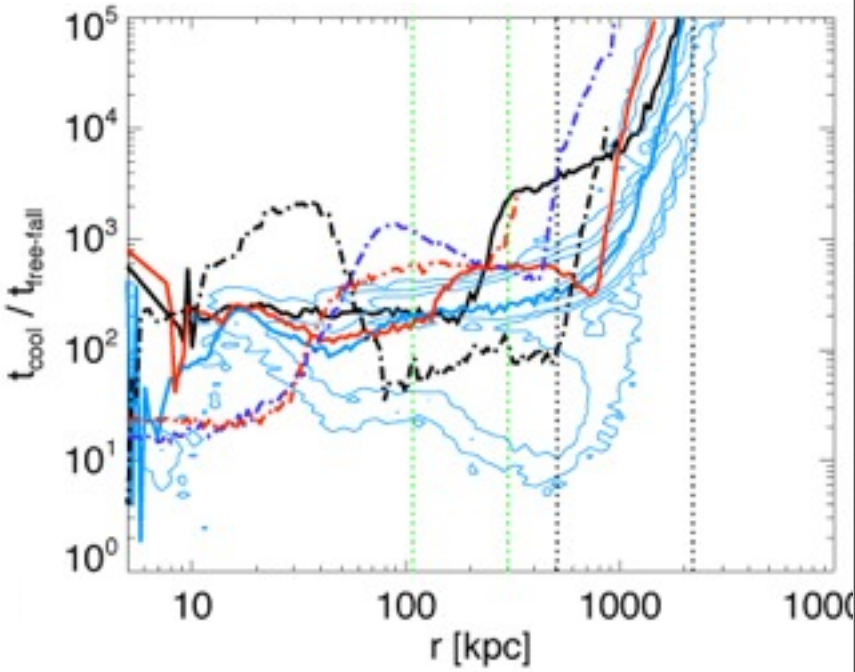
- (1) “Complete” quenching from a single event
  - energetics might be ok...
  - high redshifts: densities larger, cooling in filaments
  - can it really work for a Hubble time?

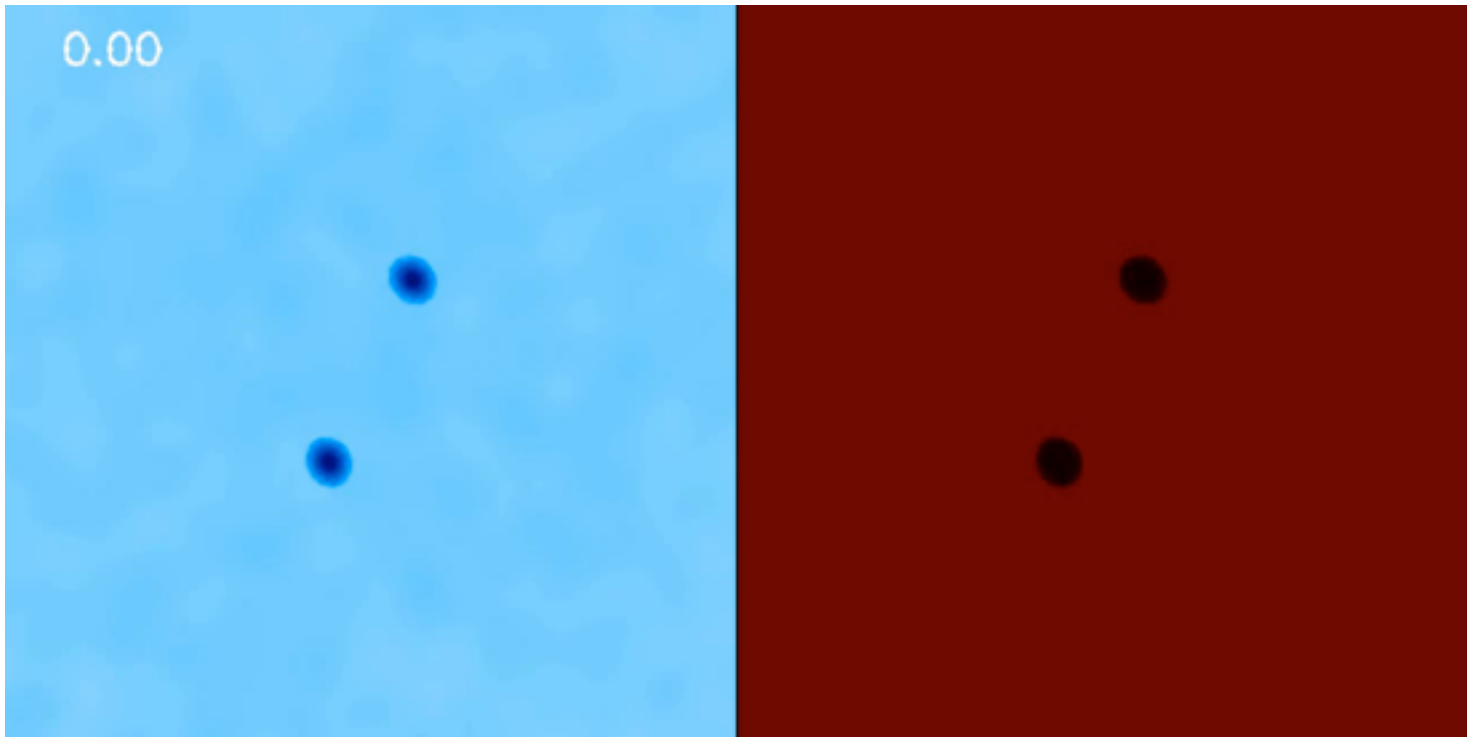


- (2) Buying time
  - expel cold gas at the end of the merger
  - heat remaining gas to much larger t_cool
  - only need ~couple Gyr to “naturally” develop a hot halo
  - still needs “radio mode” when that hot halo is formed



- (3) Hot halos from merger feedback
  - quasar/starburst heats gas to t_cool >> t_dyn
  - merger simulations end up with quasi-static, pressure supported gas equilibrium inside R_vir
  - new gas will shock: don't need to "pre-heat" everything





Summary

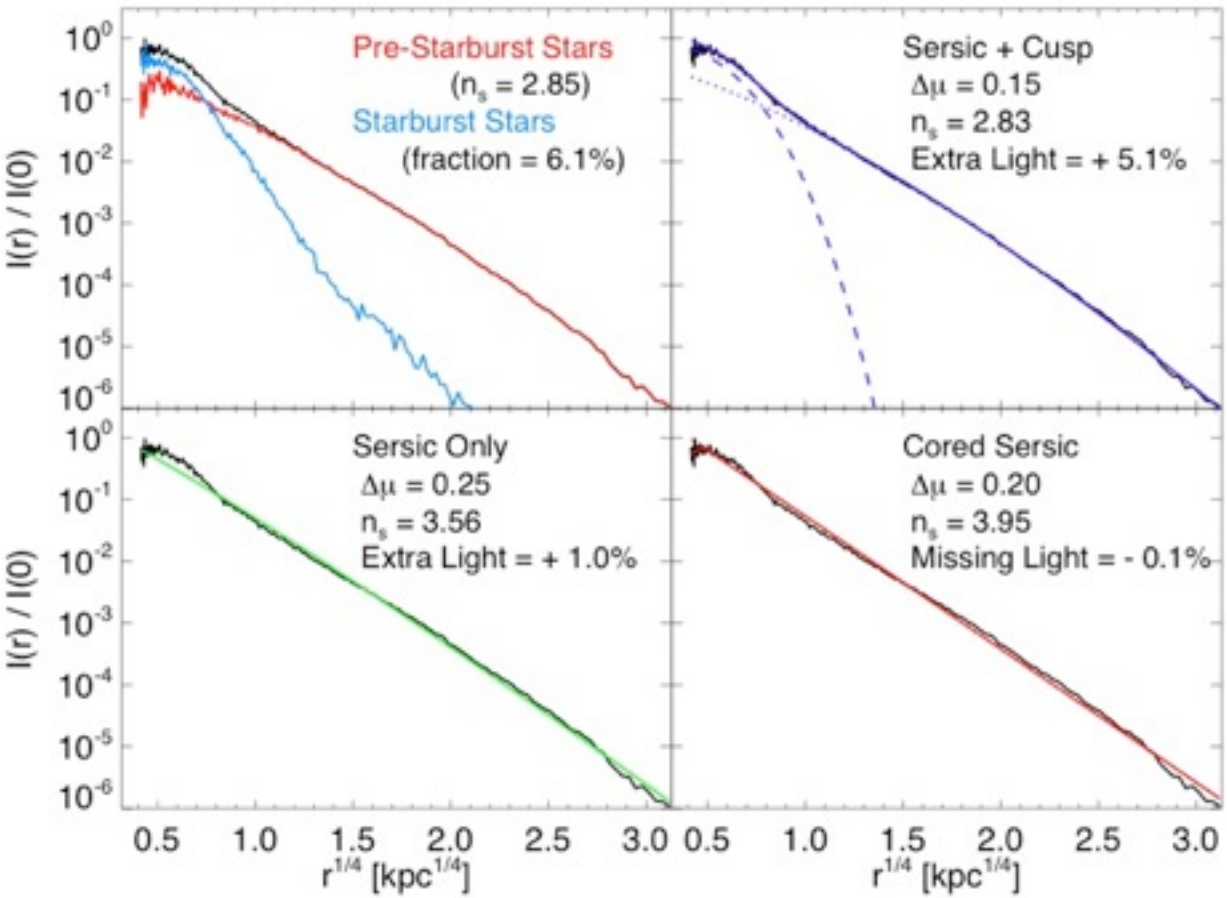
- Models where merger history supplements quenching make robust, qualitatively distinct predictions
  - Detailed observations can break degeneracies
  - Compared to models where a simple halo mass threshold or secular mechanisms set quenching, only the merger model appears to match these observations:
    - Bivariate red fraction (vs. M_halo & M_gal)
    - High-z passive populations
    - Elliptical dichotomy
    - Evolution of color-morphology-density relations

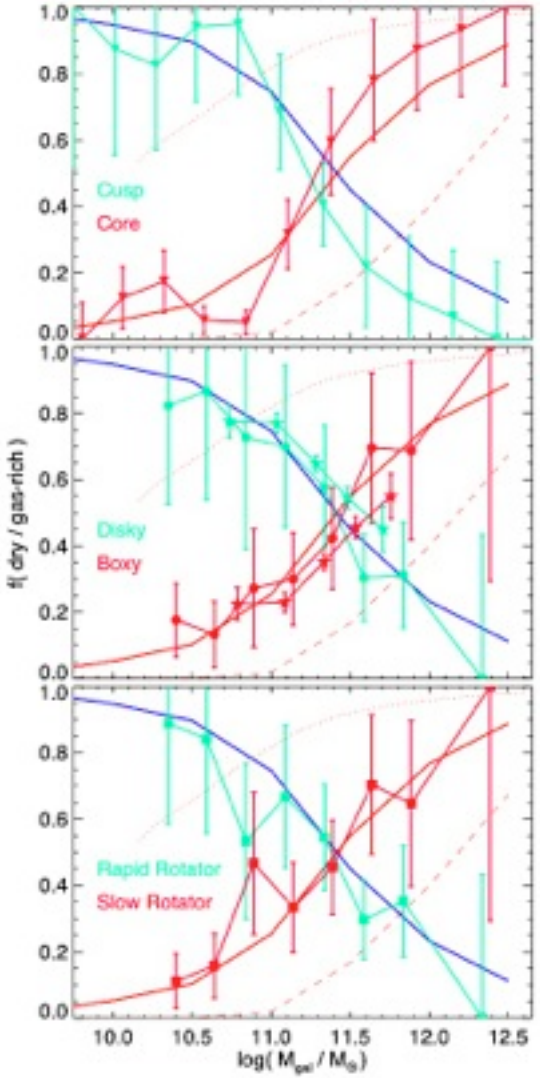
- Mergers work *with* hot halos
  - Buy time for hot halos to develop
  - Directly shock low-mass systems to “hot halo” mode

- Caveats:
  - Satellites
  - Secular AGN fueling & pseudobulge formation are probably important: M_bulge < 10^10 M_sun, M_bh <~ 10^7 M_sun

Structure in Elliptical Light Profiles

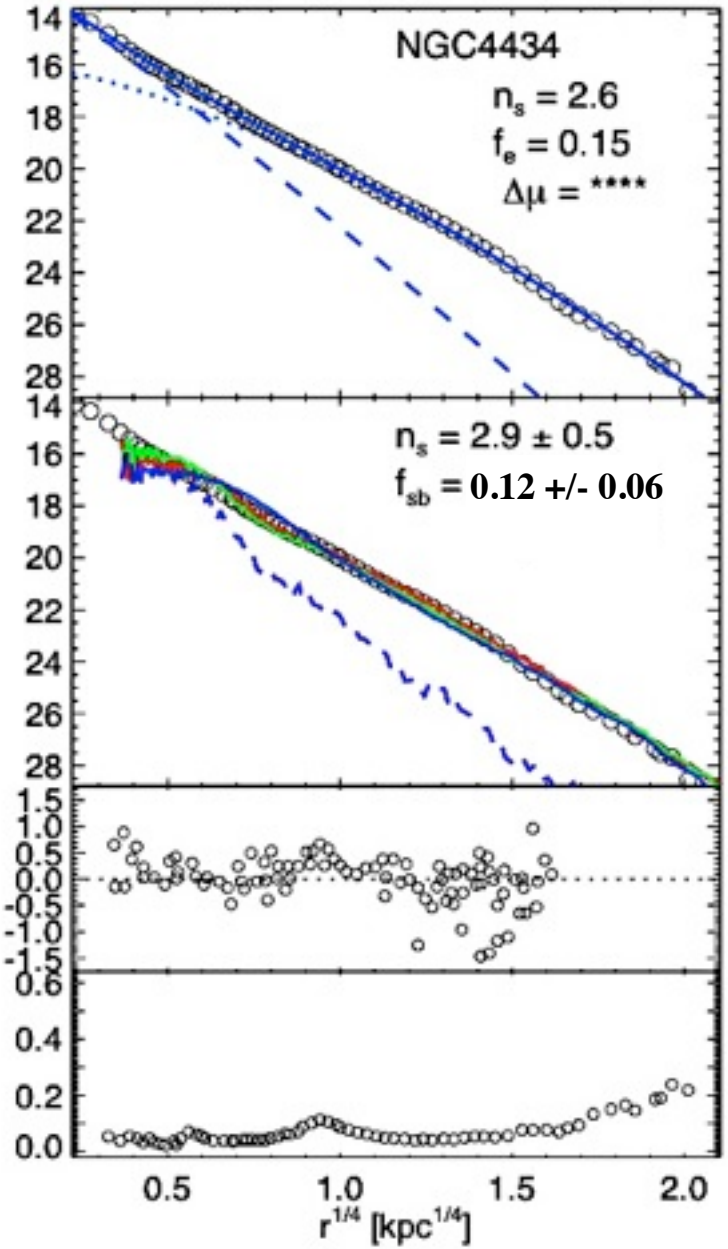
RECOVERING THE GASEOUS HISTORY OF ELLIPTICALS

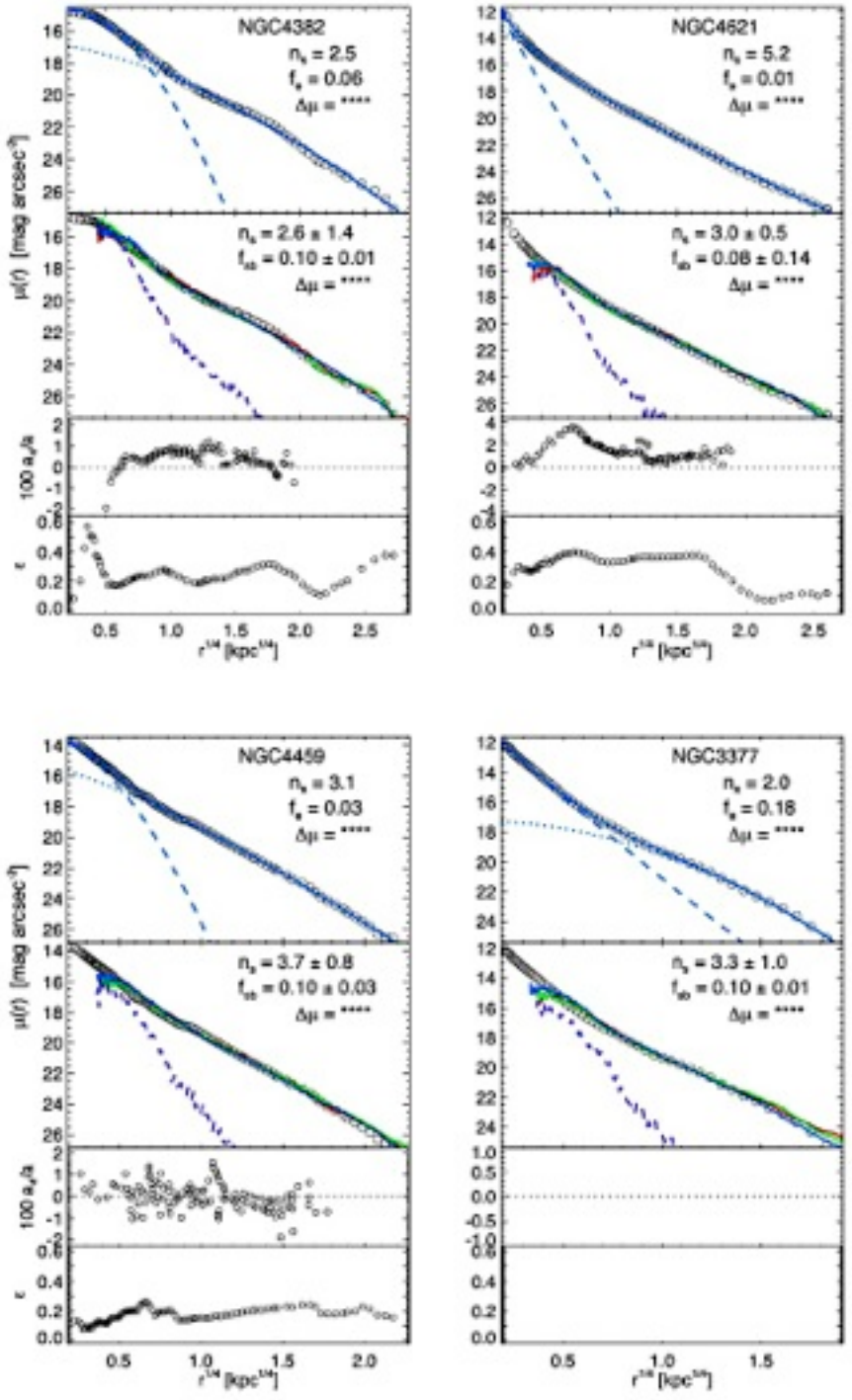




Structure in Elliptical Light Profiles

RECOVERING THE ROLE OF GAS





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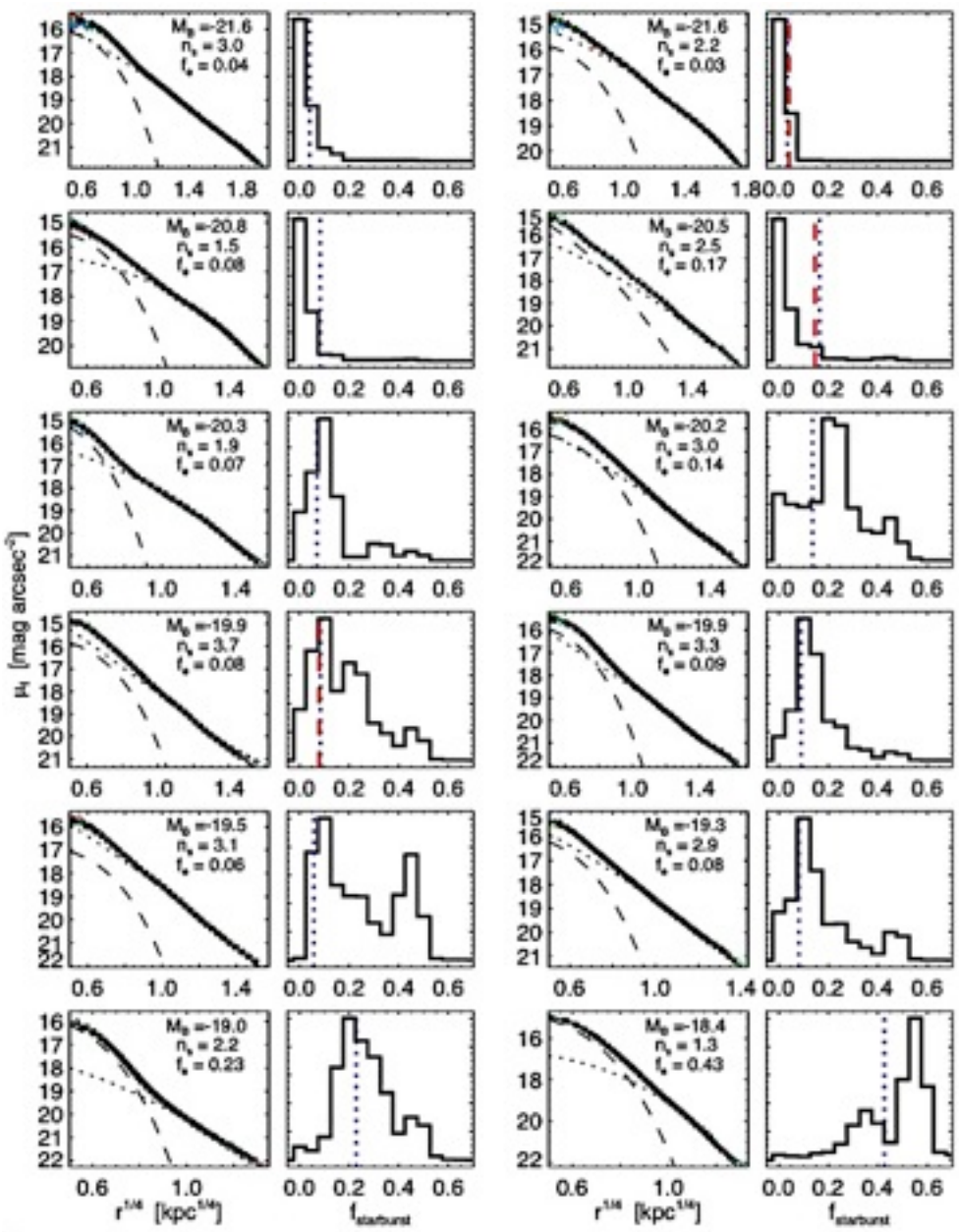

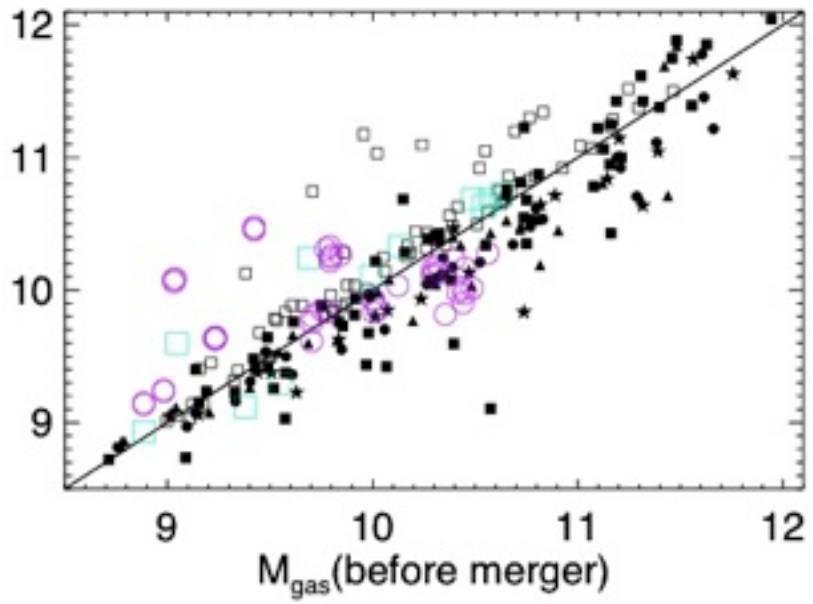

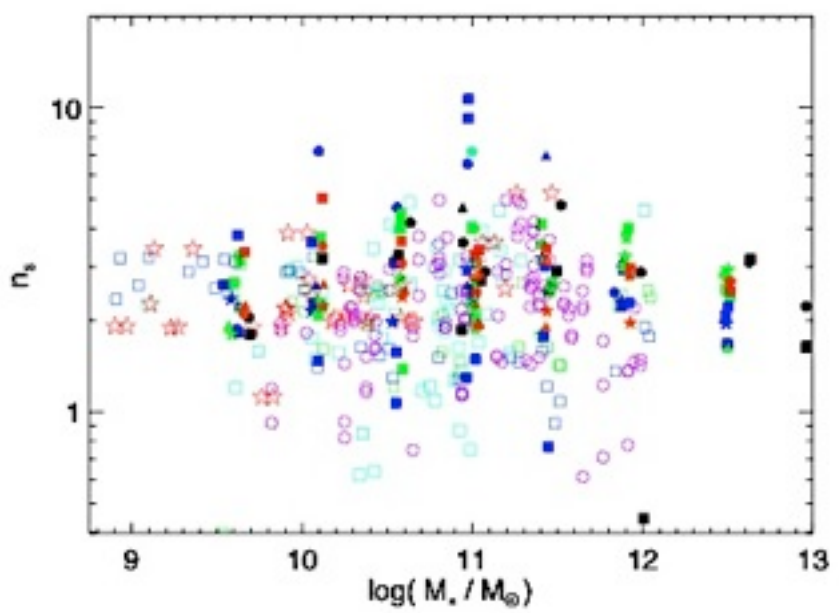

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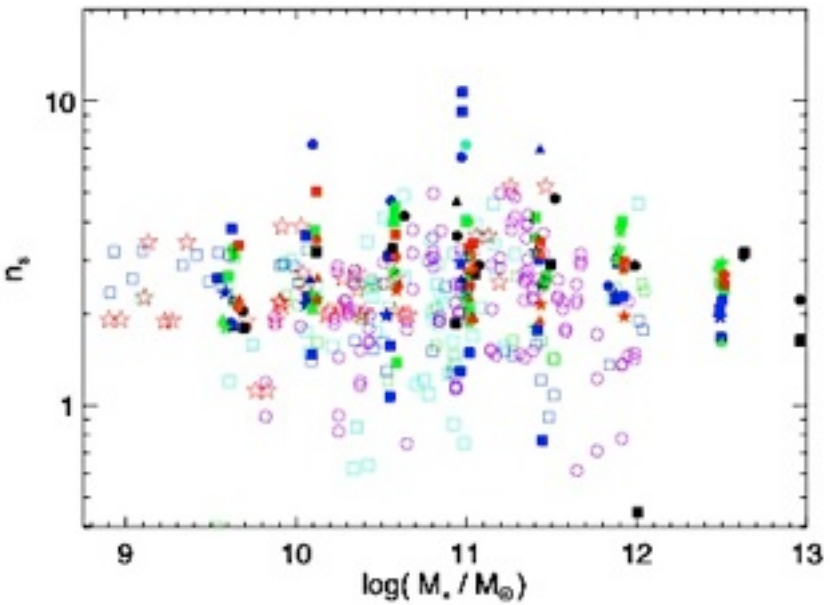

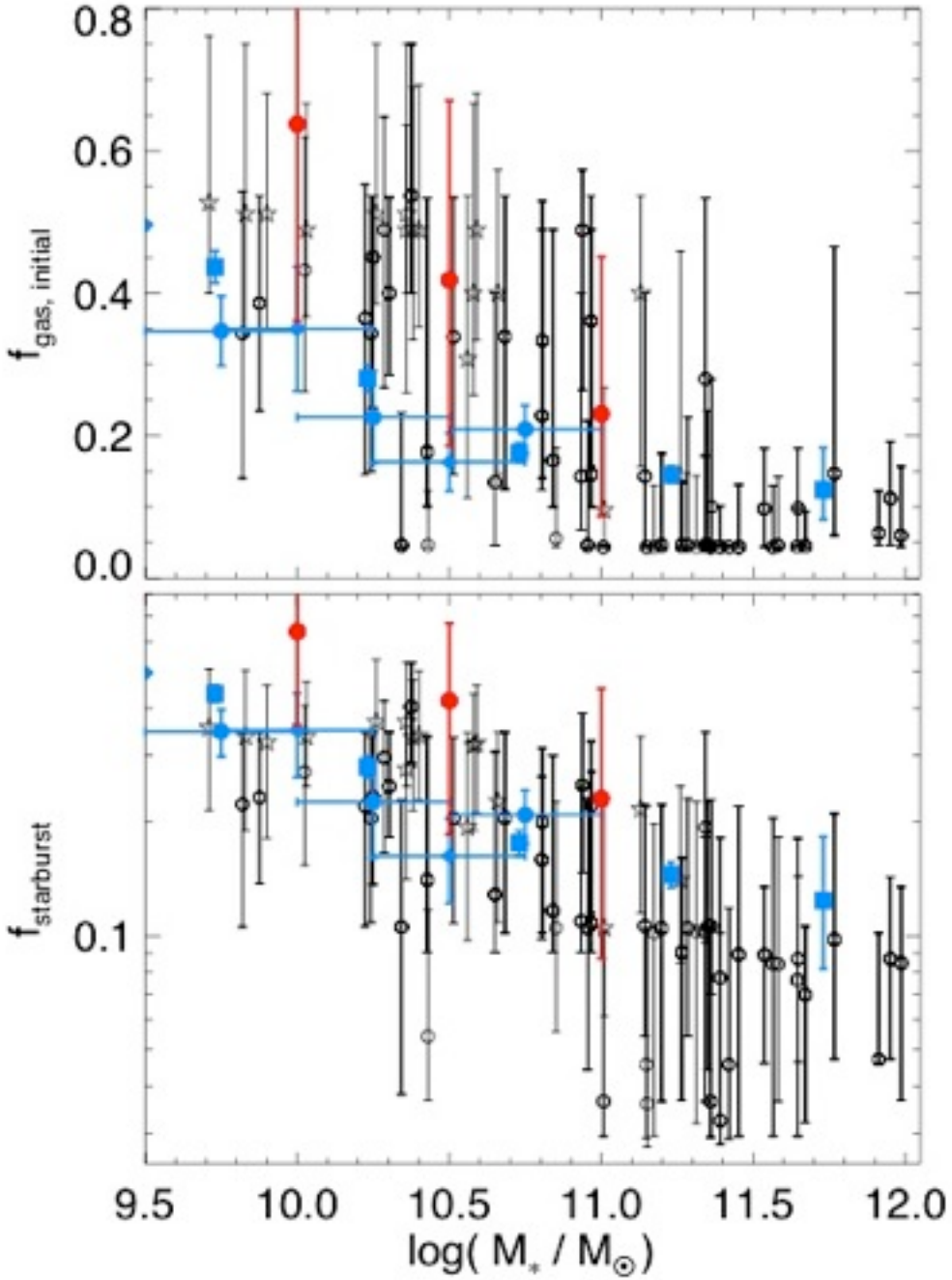

Structure in Elliptical Light Profiles

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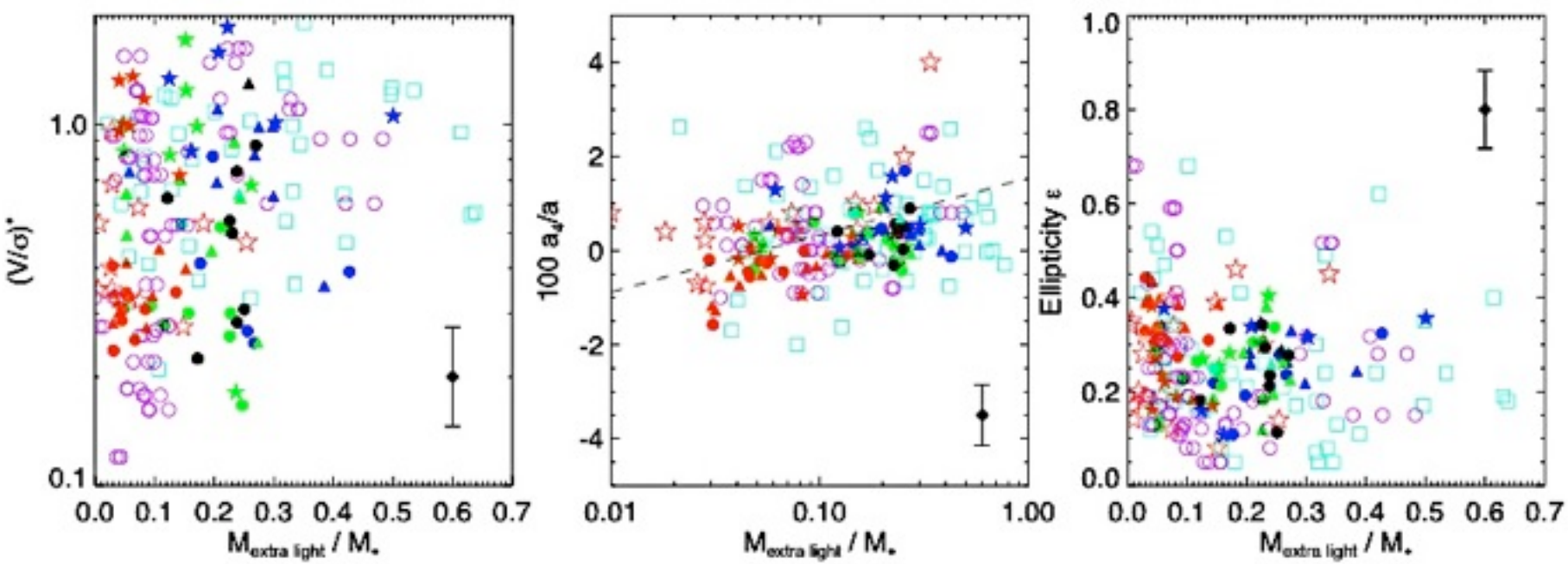

Structure in Elliptical Light Profiles

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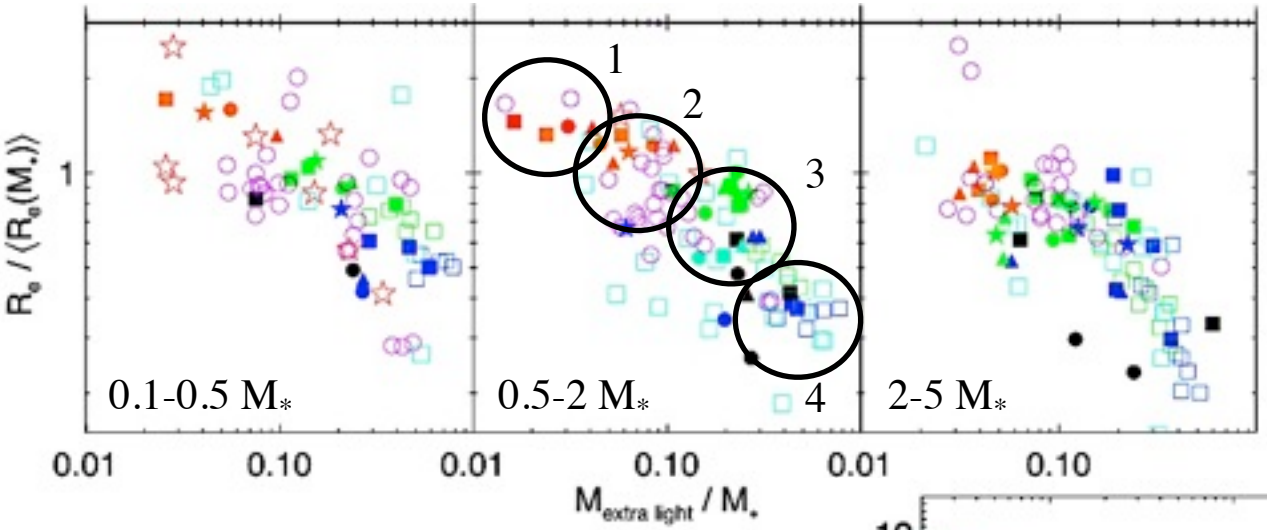
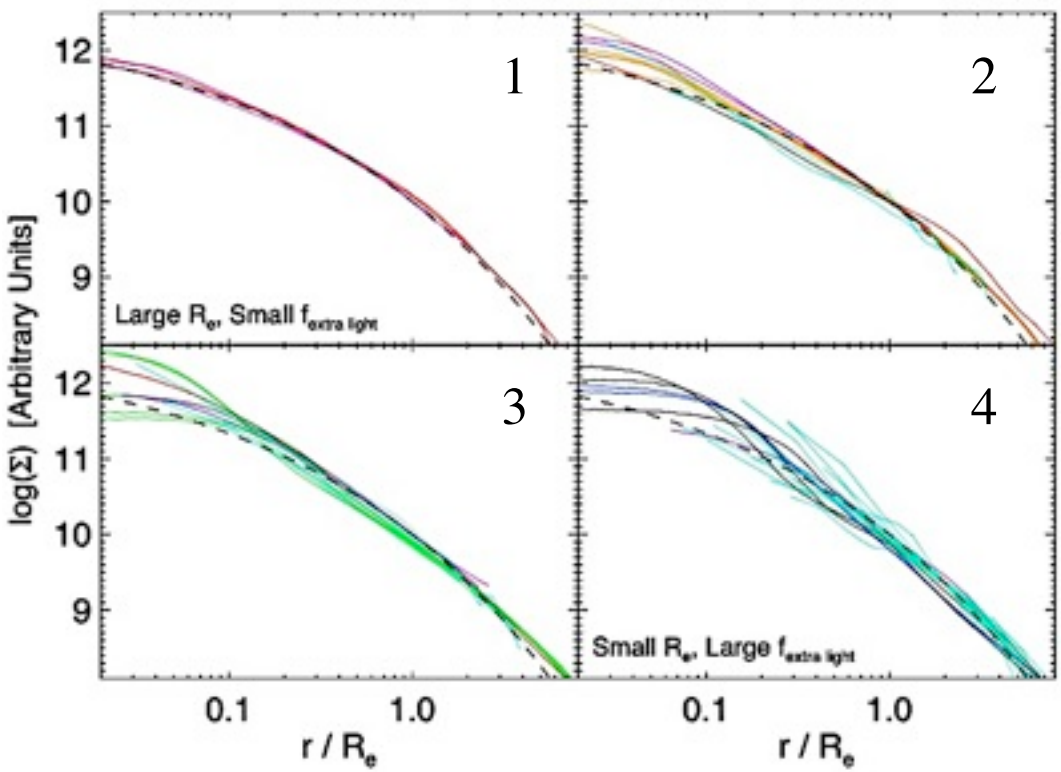
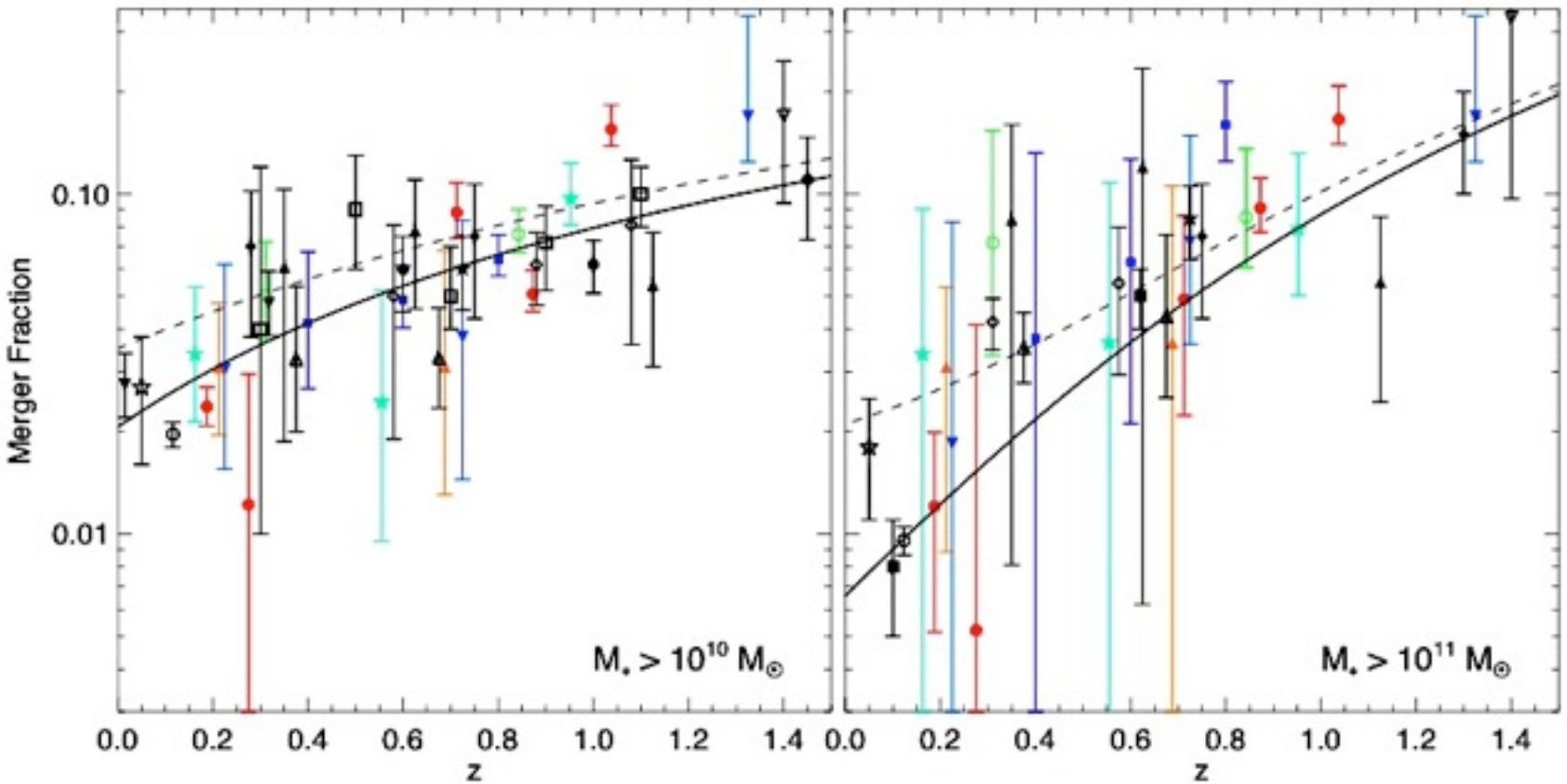




Motivation

CIRCUMSTANTIAL EVIDENCE

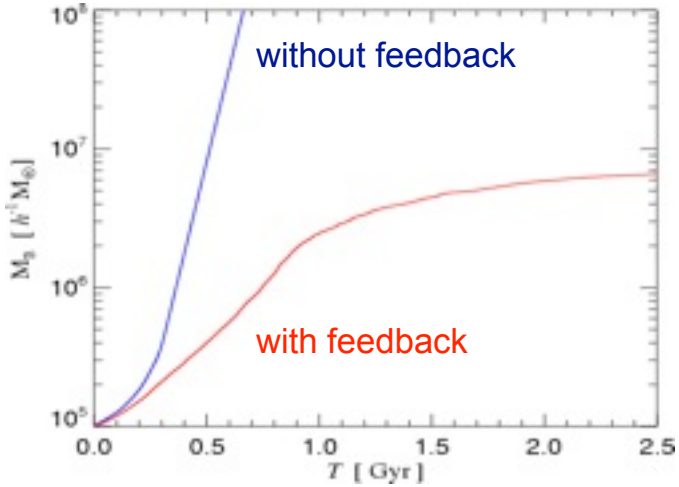
Bell+06; Lotz+06; Lin+04;
Patton+02; Conselice+03



Hopkins, Bundy+ 06

The Role of "Quasar" Feedback

CORRELATION VS. CAUSALITY?

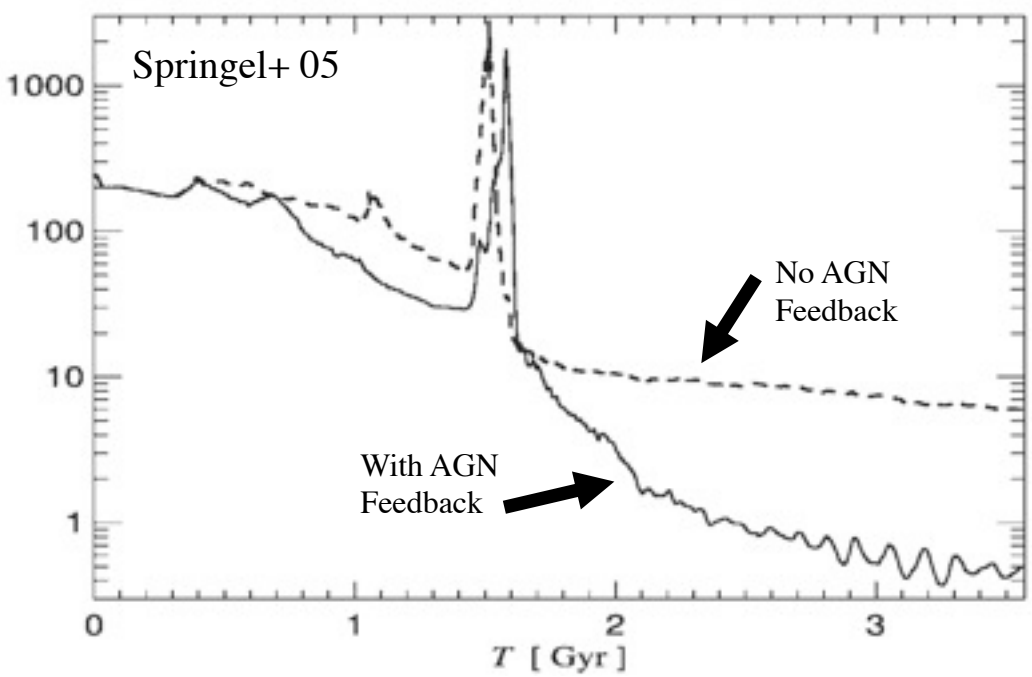


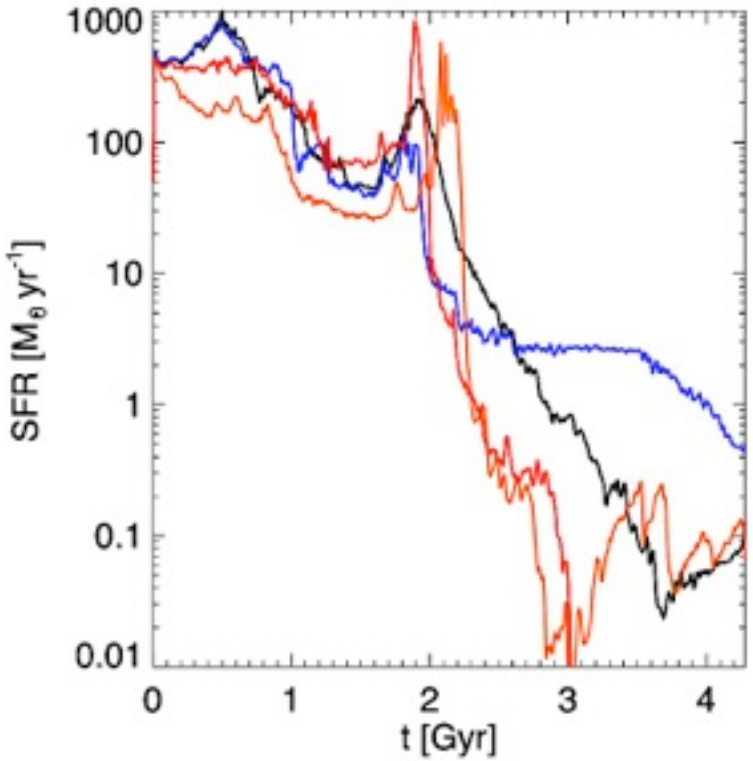
(see also Fontanot+ 06; Volonteri+ 06)

"Quasar" feedback *must* exist...

...and it *does* exist

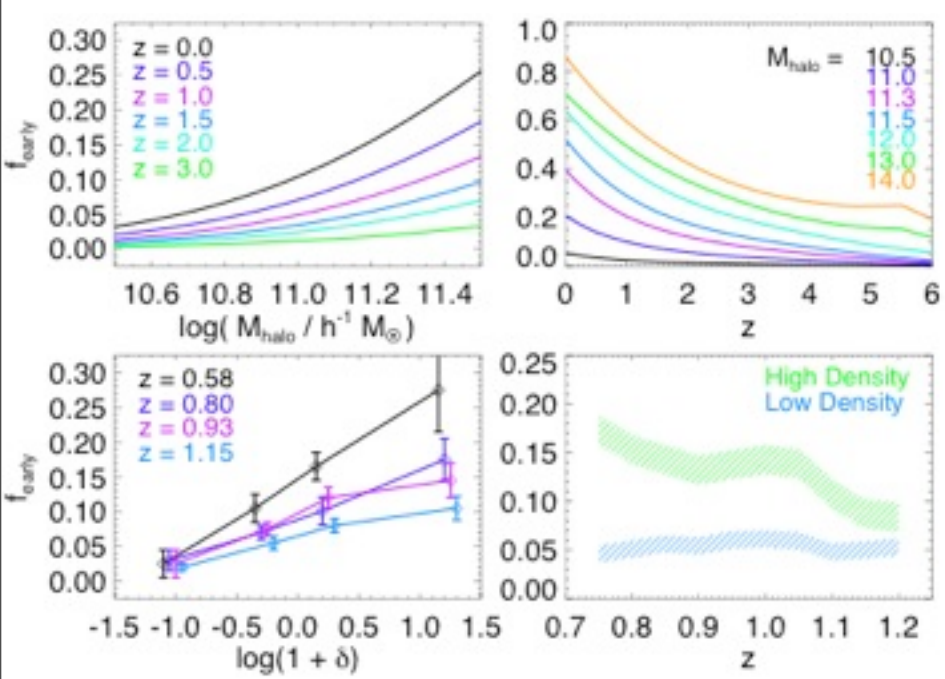
(but on what level?)

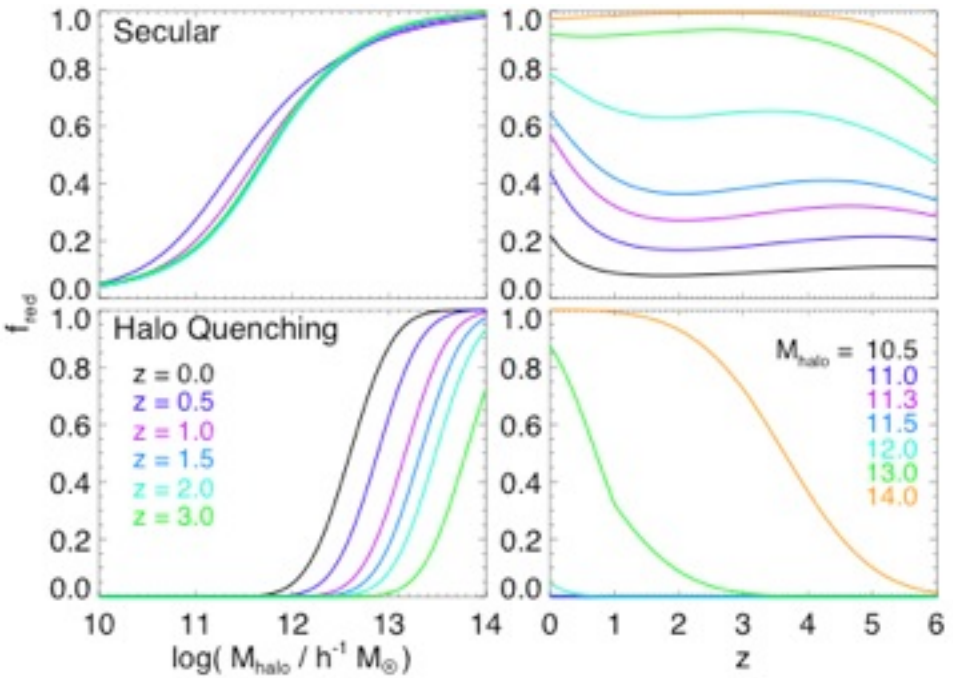




Comparing Quenching Models

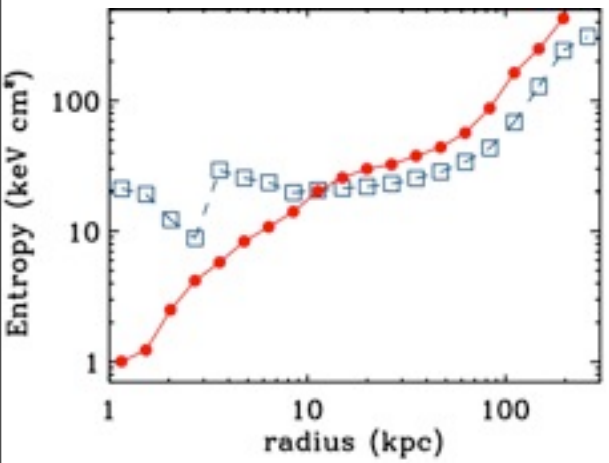
COLOR-MORPHOLOGY-DENSITY RELATION EVOLUTION

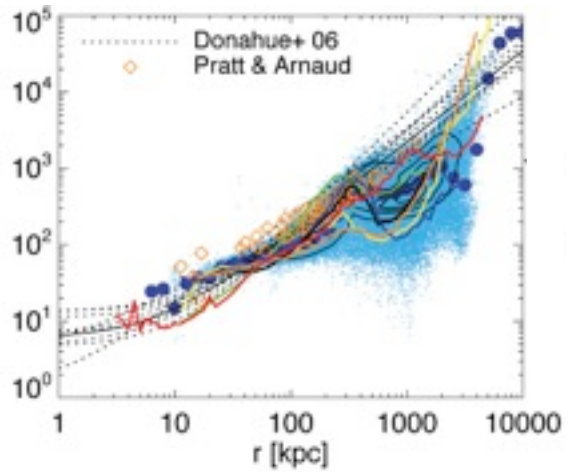


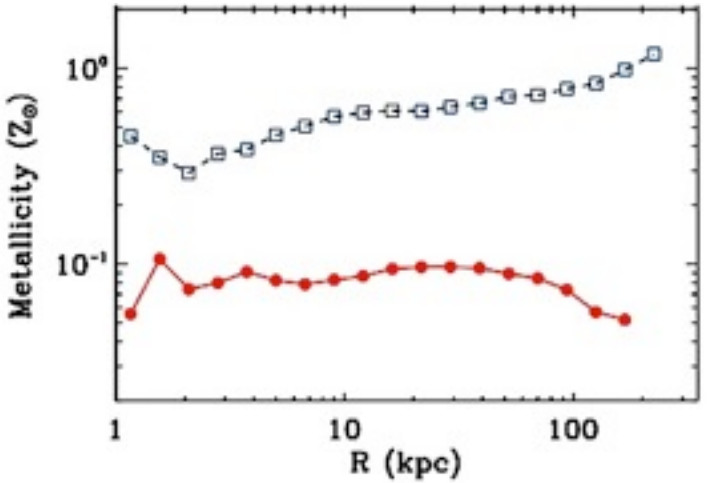


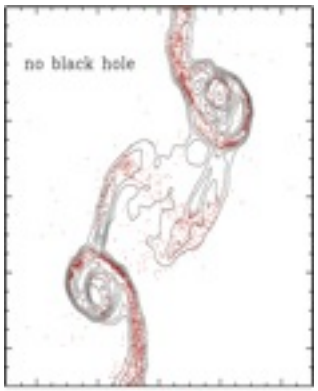
The Role of "Quasar" Feedback

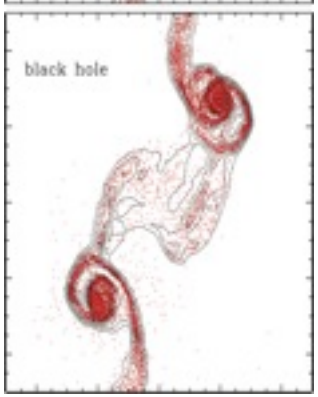
CORRELATION VS. CAUSALITY?

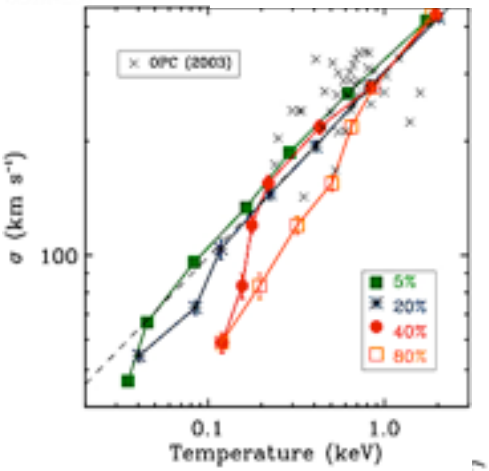


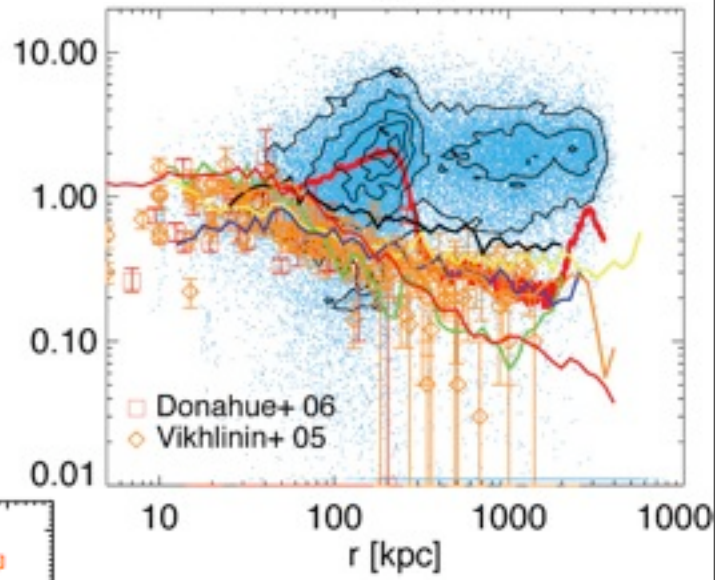


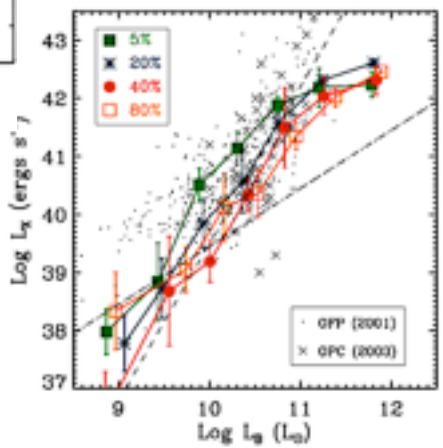


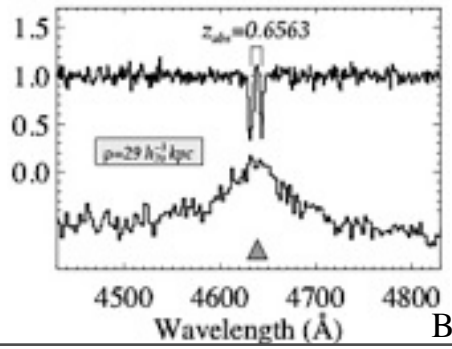












Cox+ 06

Hopkins+ 06 (in prep)

Bowen+ 06