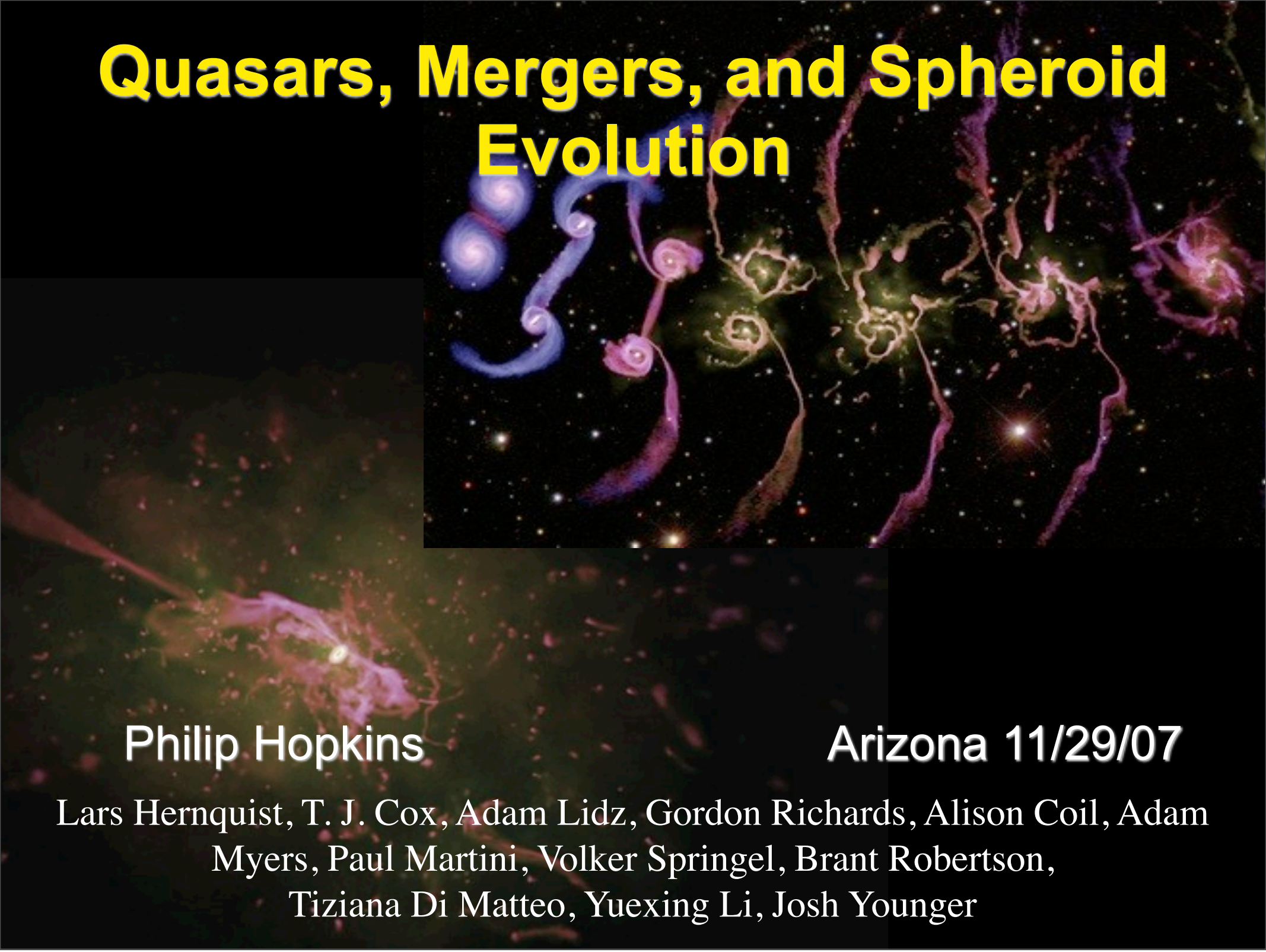
Quasars, Mergers, and Spheroid Evolution



Philip Hopkins

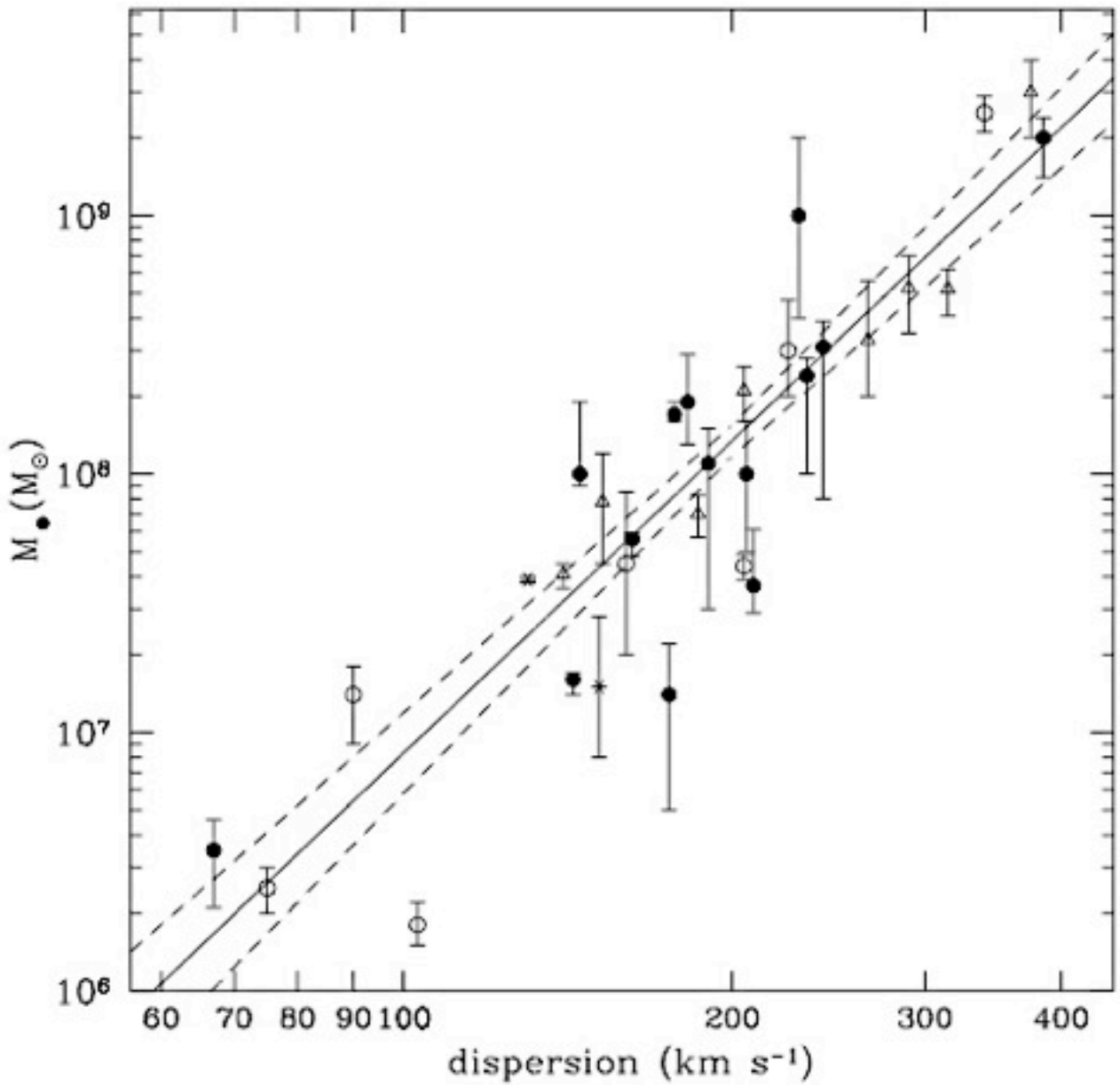
Arizona 11/29/07

Lars Hernquist, T. J. Cox, Adam Lidz, Gordon Richards, Alison Coil, Adam Myers, Paul Martini, Volker Springel, Brant Robertson, Tiziana Di Matteo, Yuexing Li, Josh Younger

Motivation

HOW DO BLACK HOLES GROW?

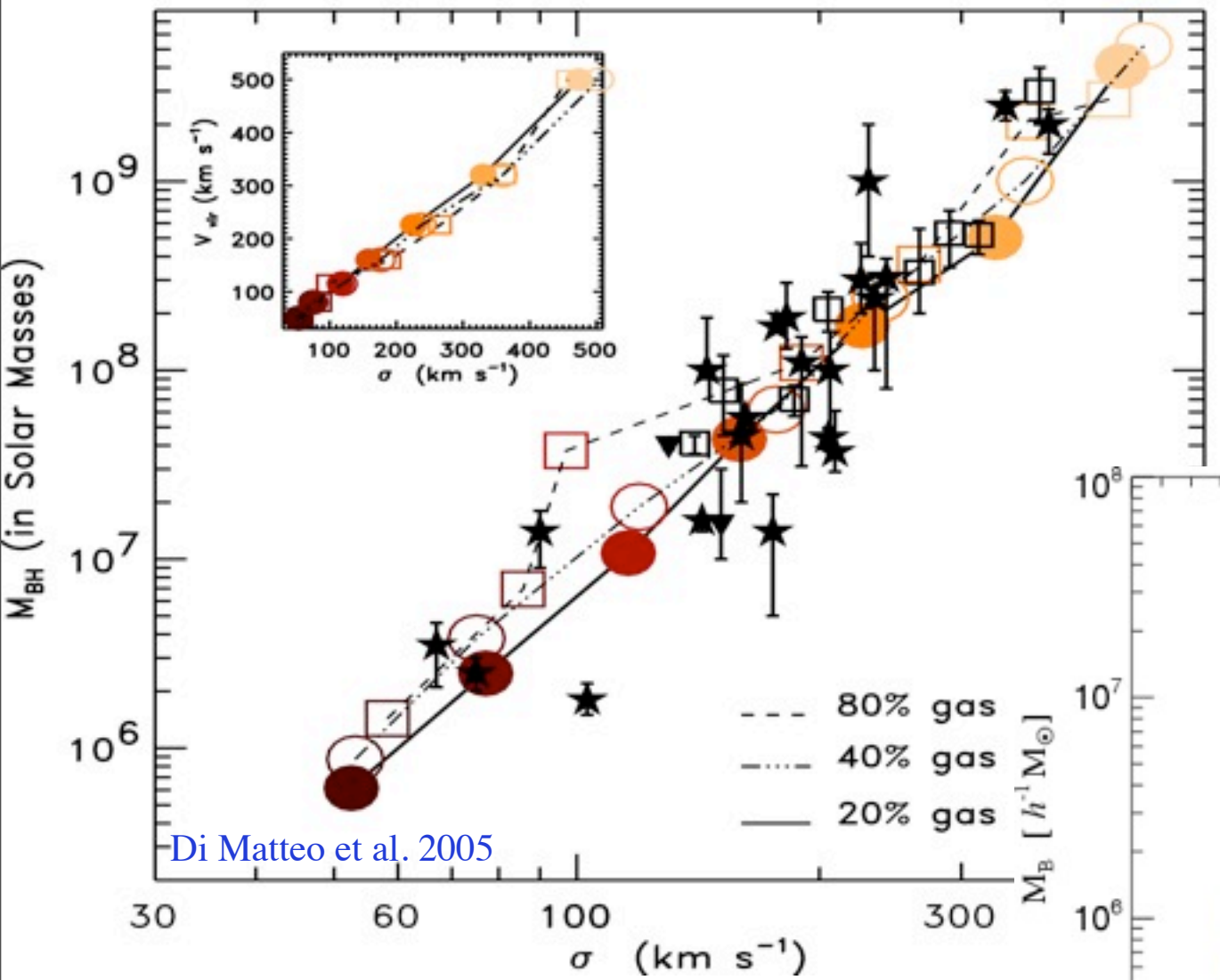
- Black holes somehow sensitive to their host bulges:



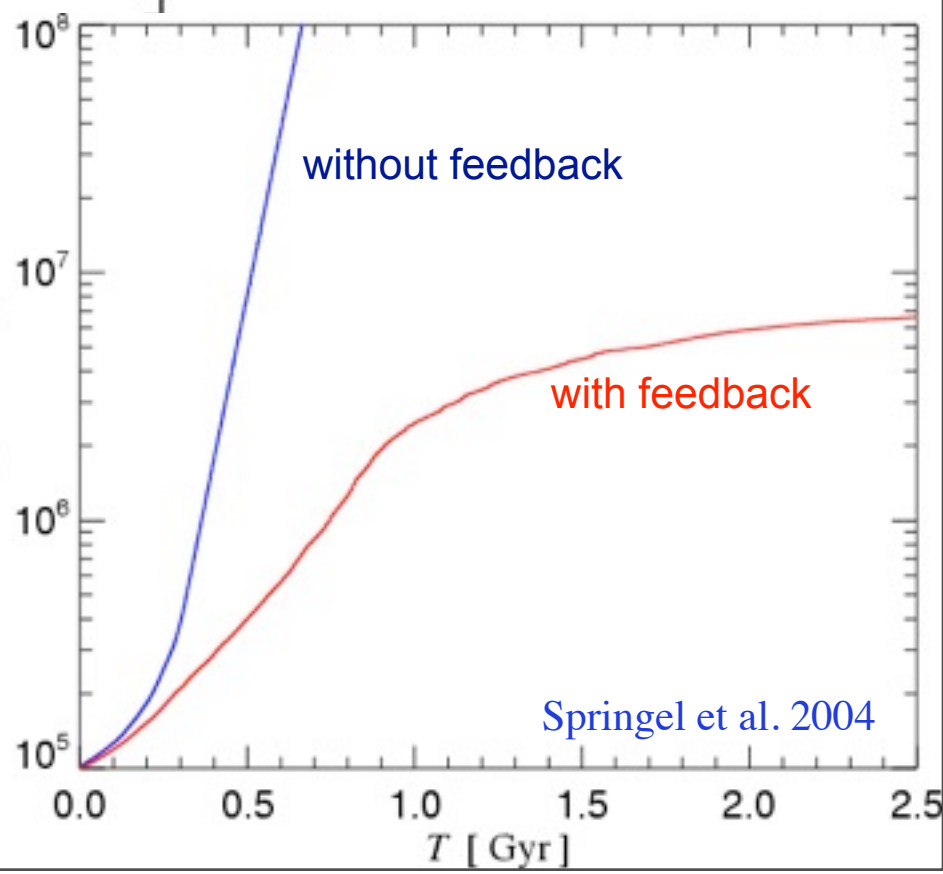
Ferrarese & Merritt ’00,
Gebhardt+ ’00
Tremaineet al. ‘02

M-sigma Relation Suggests *Self-Regulated* BH Growth

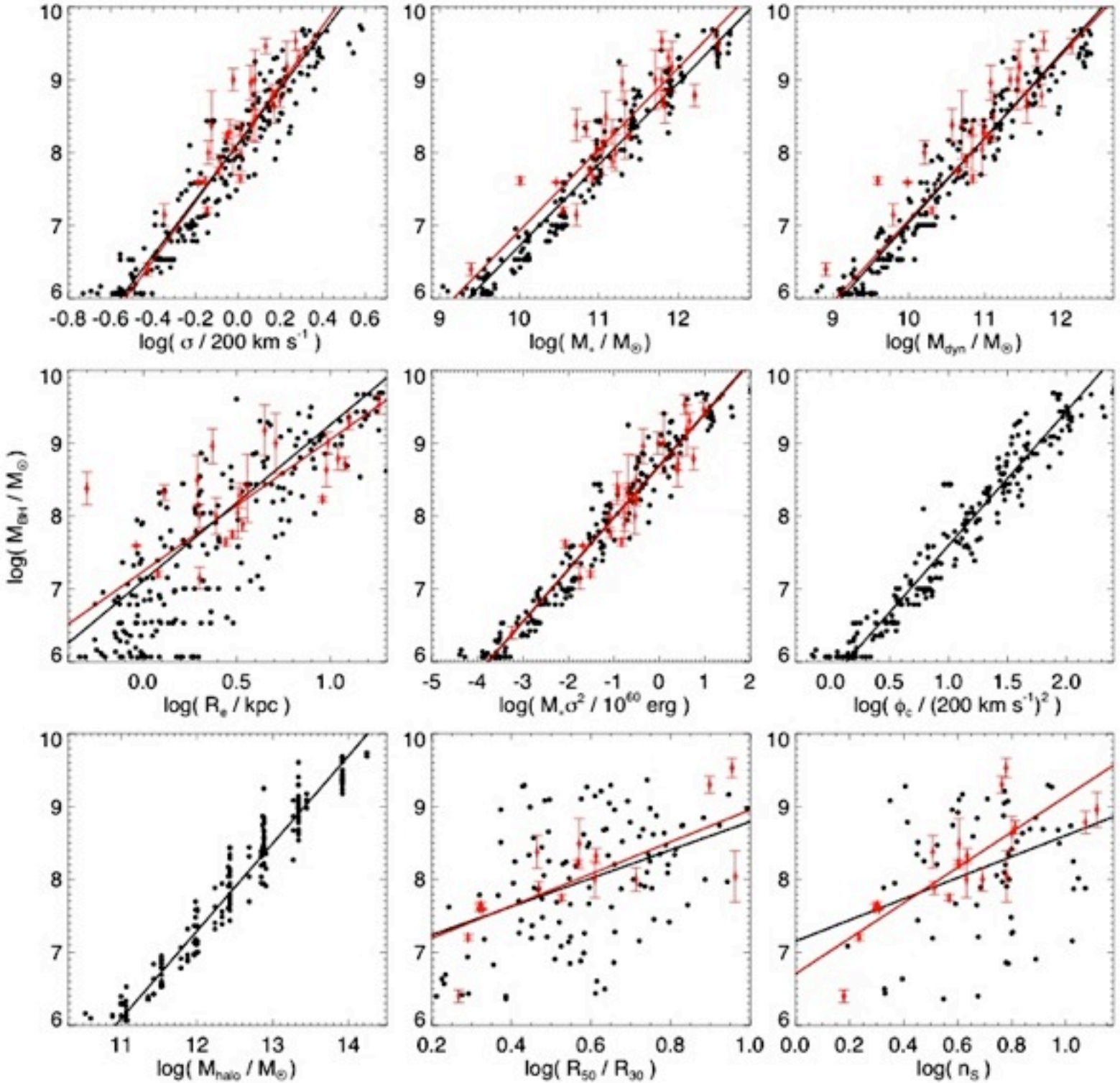
PREVENTS RUNAWAY BLACK HOLE GROWTH



Black hole growth



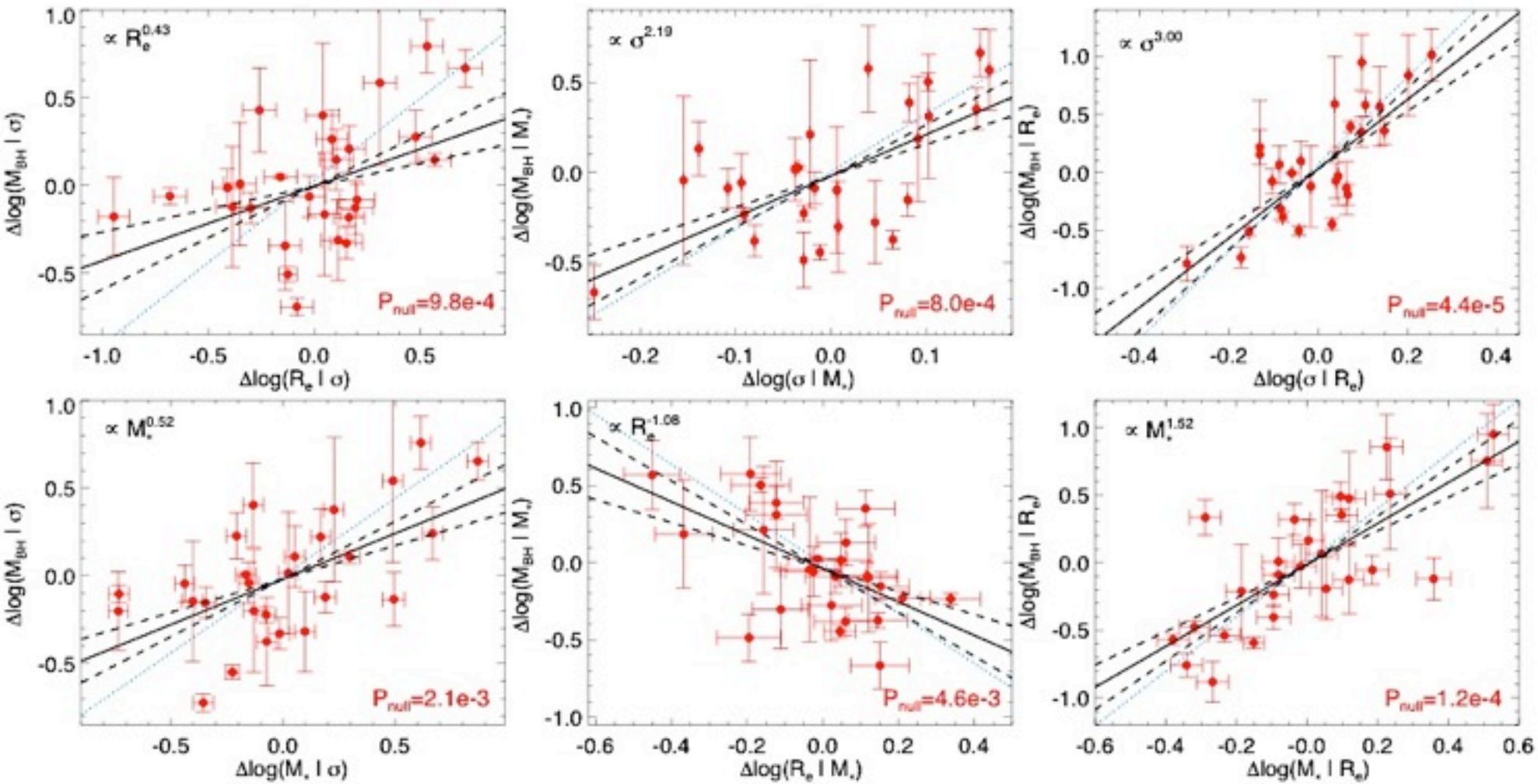
If only ~1% of gas mass lost angular momentum, would get runaway accretion!


log(M_BH / M_⊙)
log(σ / 200 km s^-1)
log(M_* / M_⊙)
log(M_dyn / M_⊙)
log(R_e / kpc)
log(M_*σ^2 / 10^60 erg)
log(φ_c / (200 km s^-1)^2)
log(M_halo / M_⊙)
log(R_50 / R_90)
log(n_S)

Which Correlation Is "Most Fundamental"?

COMPARE RESIDUALS

at fixed sigma: at fixed M_bul: at fixed R_e:



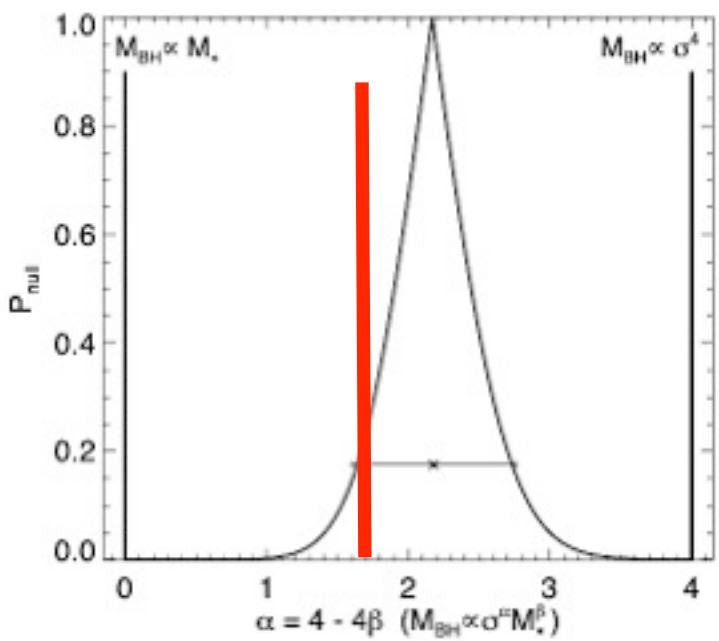
~3s significant residual trend with respect to ANY single variable correlation!

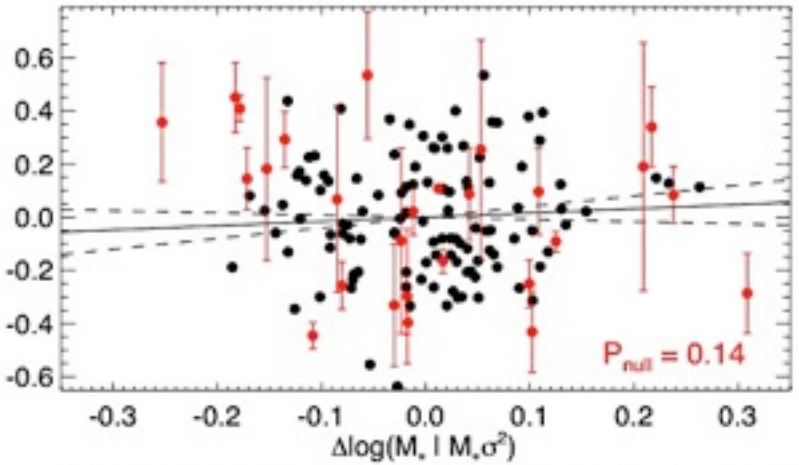
Which Correlation Is "Most Fundamental"?

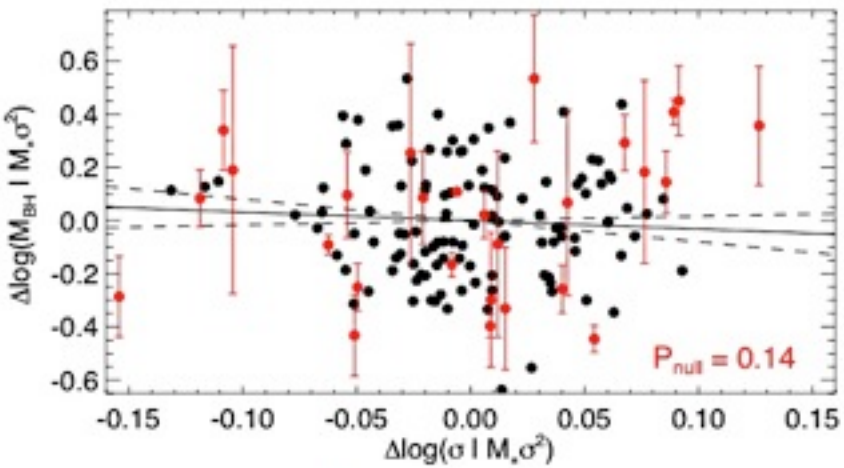
WHAT ELIMINATES THE SECONDARY VARIABLES?

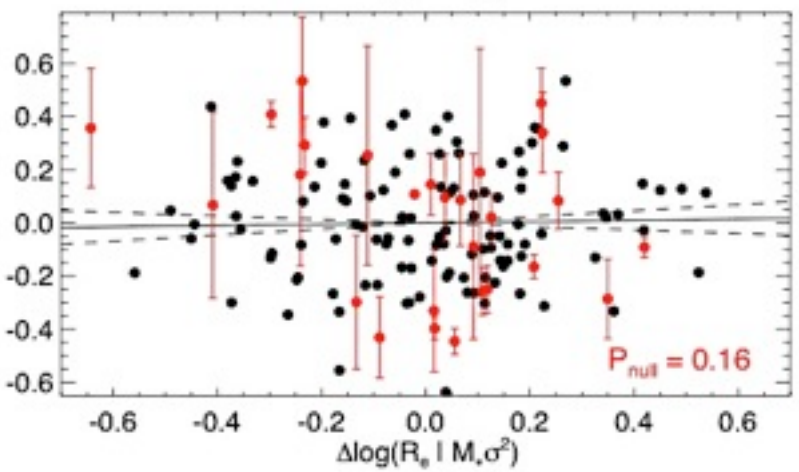
- Find a FP-like correlation:
  - $M_{bh} \sim M_{bul}^{a}\ s^{b}$
  - $M_{bh} \sim R_e^{a}\ s^{b}$
  - $M_{bh} \sim M_{bul}^{a}\ R_e^{b}$

- Roughly, bulge binding energy:
  - $M_{bh} \sim E_{binding}^{0.7\text{-}0.8} \sim (M_{bul}\ s^2)^{0.7\text{-}0.8}$



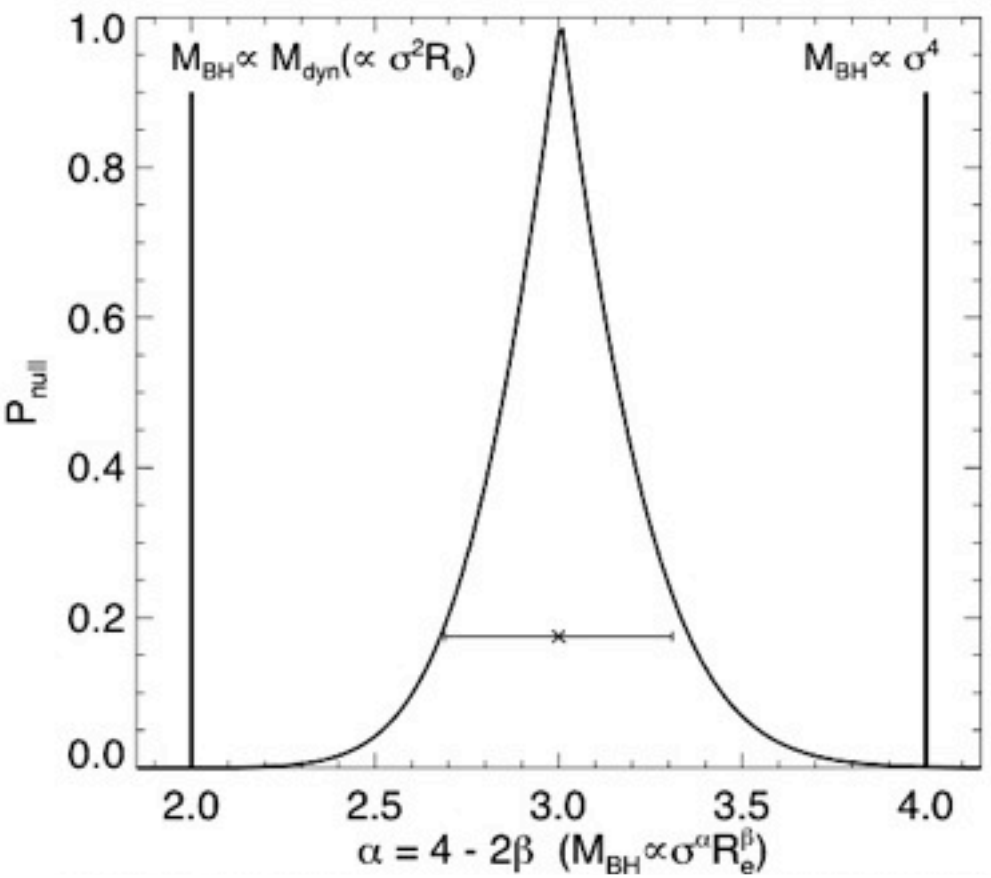


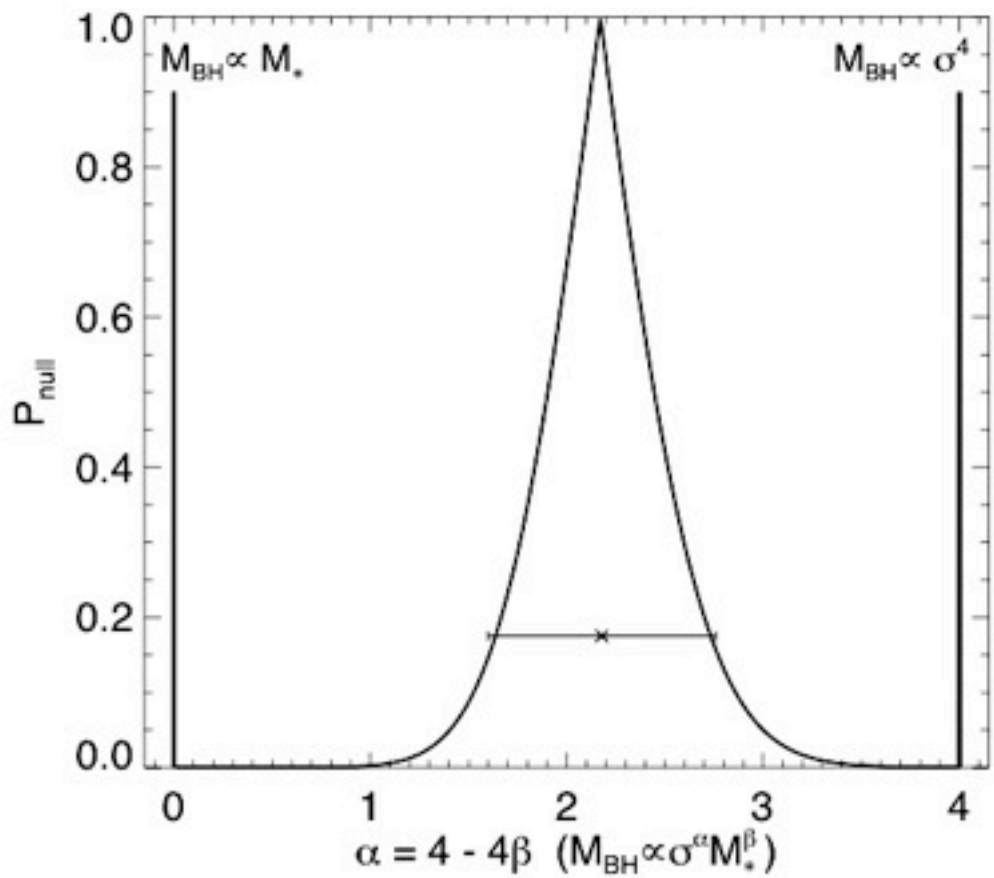




Which Correlation Is “Most Fundamental”?

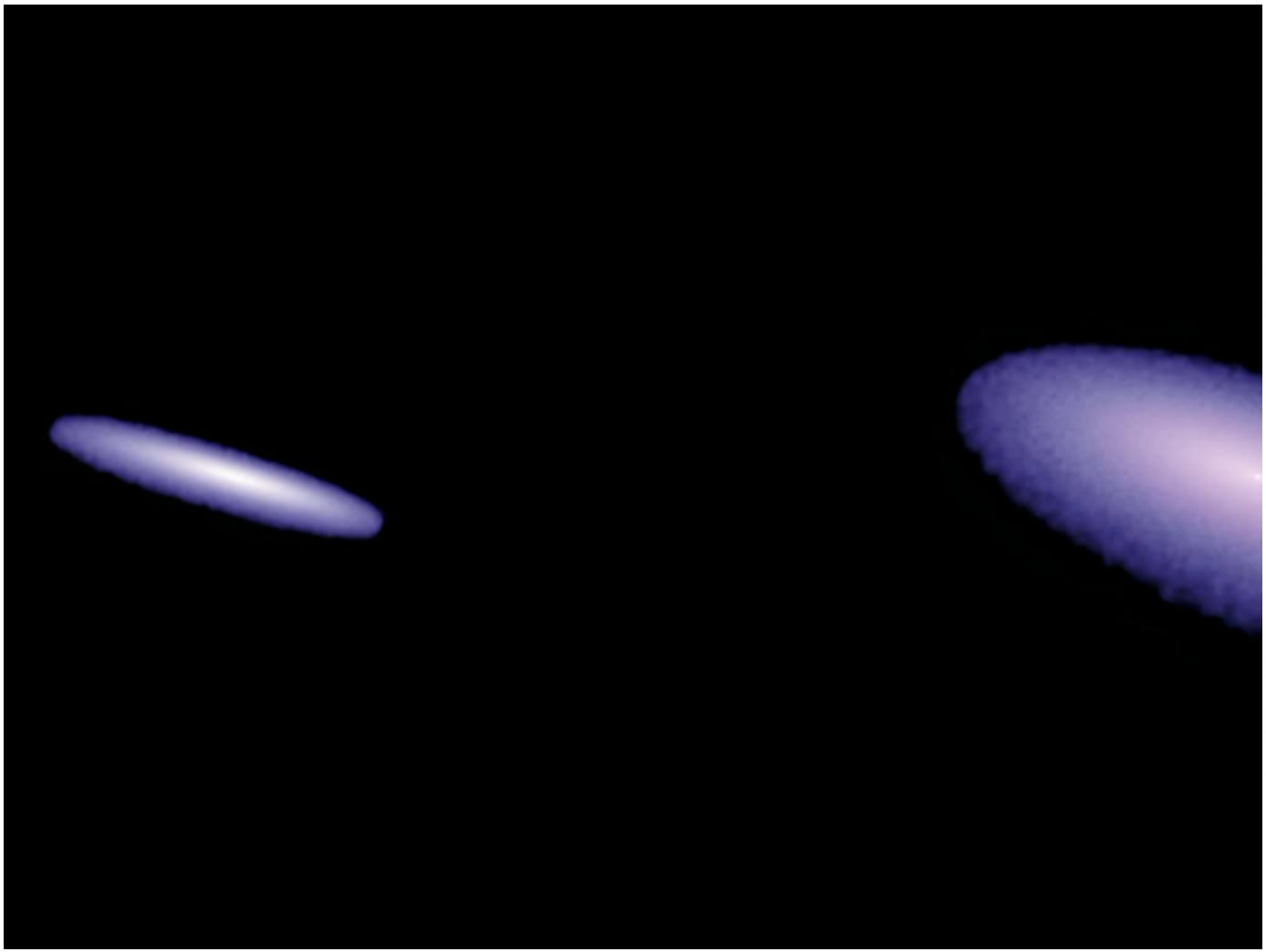
WHAT ELIMINATES THE SECONDARY VARIABLES?

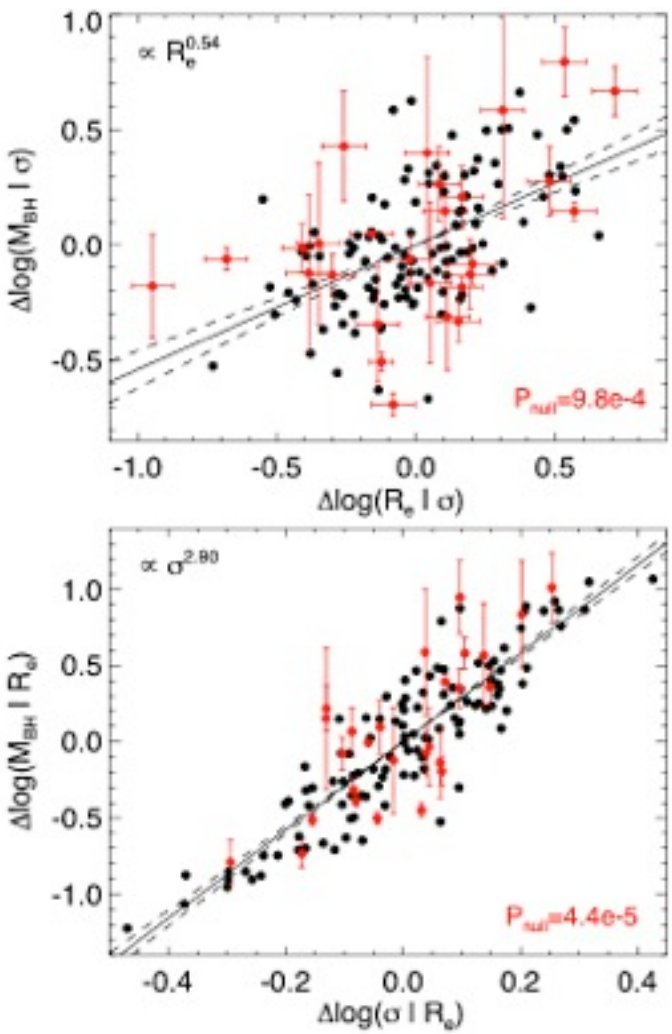




Do Feedback-Regulated Simulations Predict This?

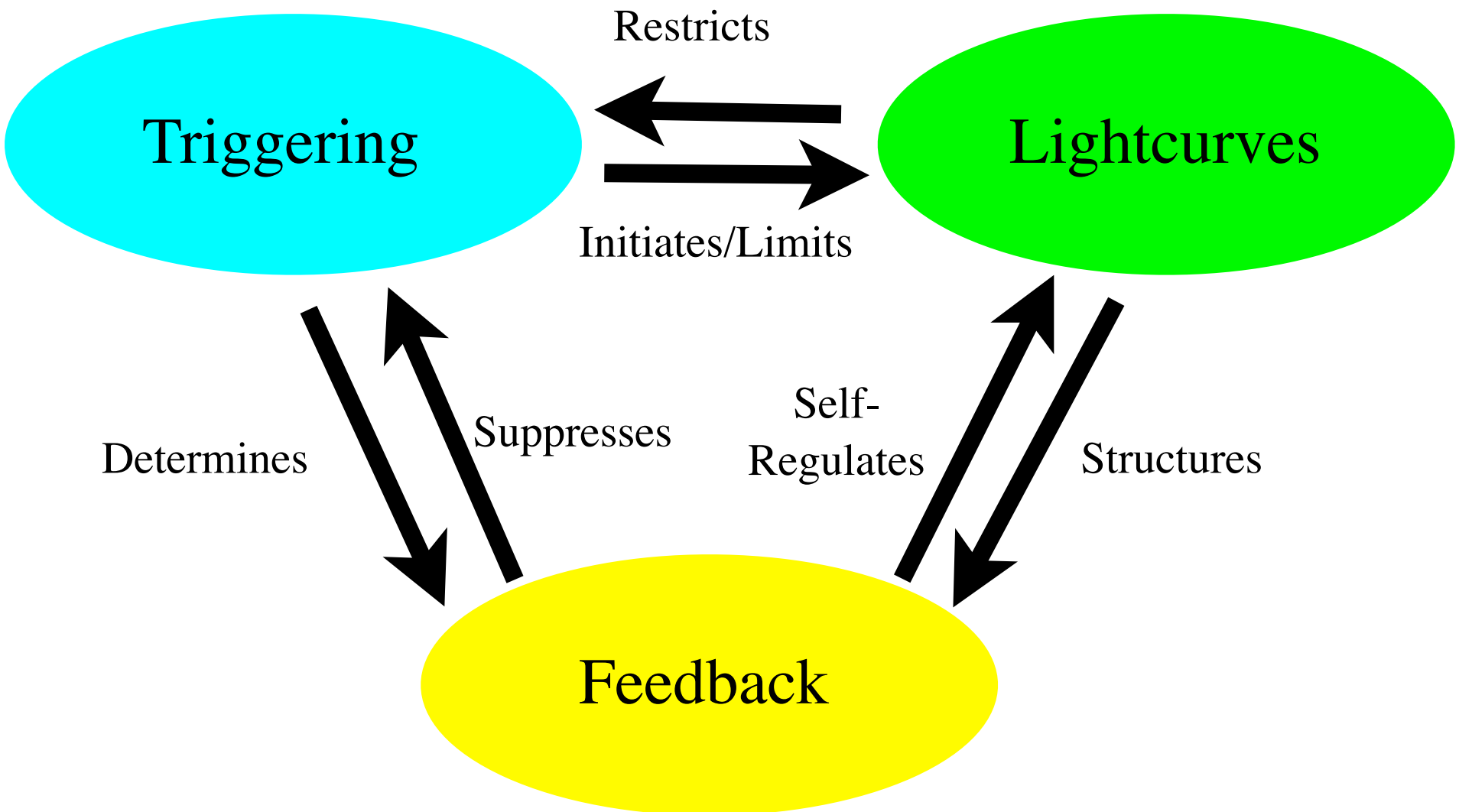
SIMPLE COUPLING OF BH RADIATED ENERGY TO SURROUNDING GAS IN A MERGER





- Supports basic Silk & Rees ’98 argument:
  - BH feedback self-regulates growth in ~fixed potential
  - only “feel” the local potential of material to be unbound

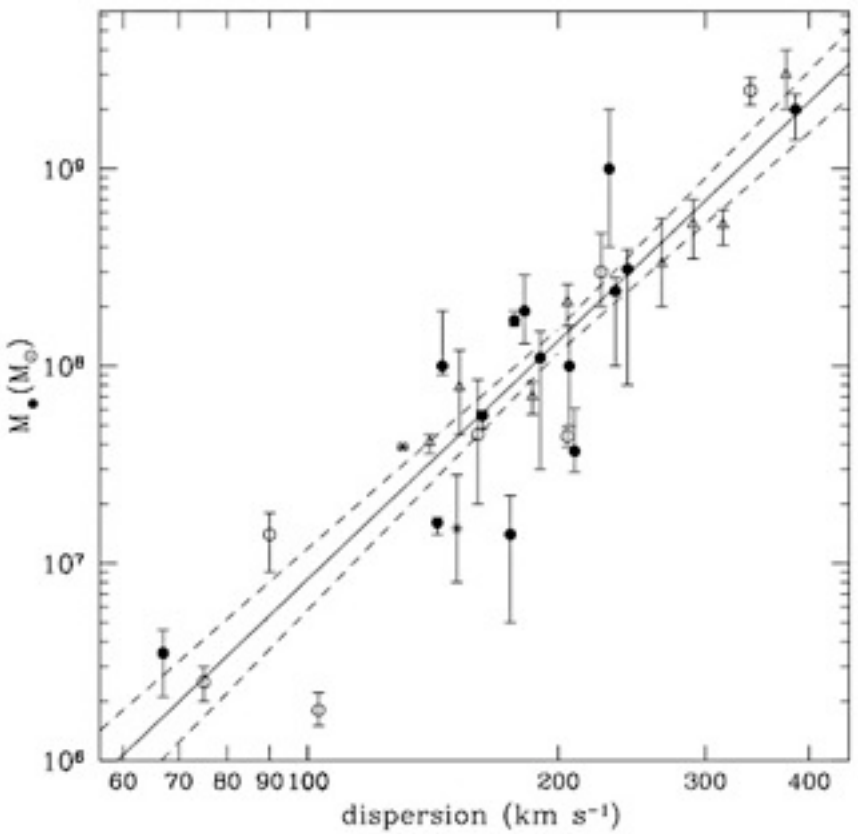
Three Outstanding (Inseparable?) Questions:



"Feeding the Monster"

WHAT CAN BREAK DEGENERACIES IN DIFFERENT FUELING MODELS?

- If BHs trace spheroids, then
  most mass added in mergers



- Other candidates must also be:
- Fast, violent
- Blend of gas & stellar dynamics
- Why?

* Soltan (1982): bulk of SMBH mass density grown tnrough radiatively efficient accretion in quasars

  → gas dynamics; rapid (~ few 10^7 years)

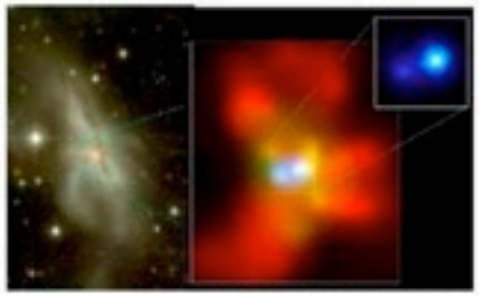
* Lynden-Bell (1967): orbits of stars redistributed in phase space by large, rapid potential fluctuations

  → stellar dynamics; freefall timescale

(c) Interaction/"Merger"

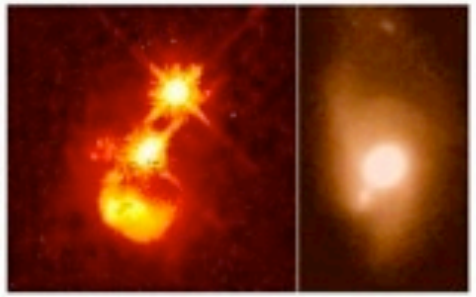
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



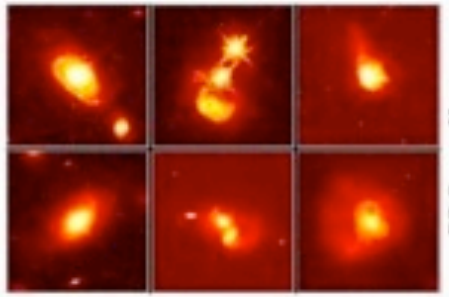
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(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

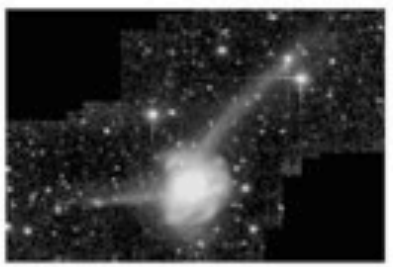


- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

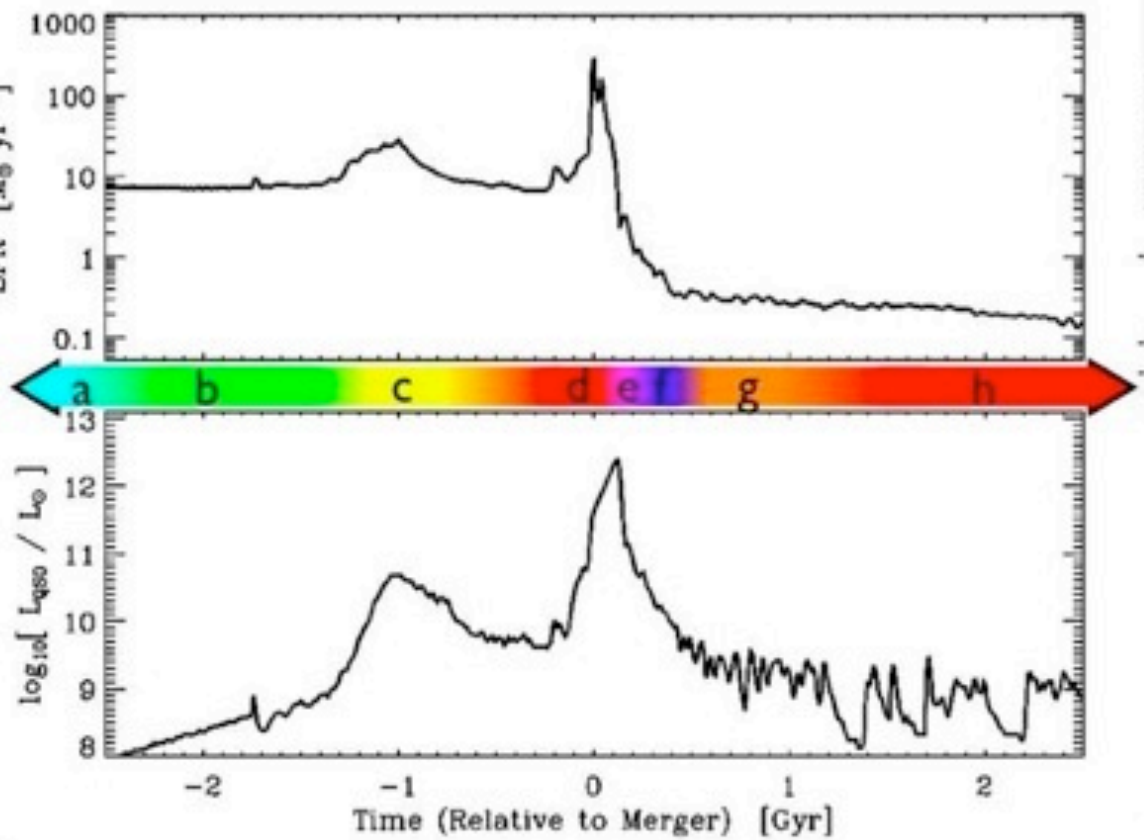
(b) "Small Group"

- 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

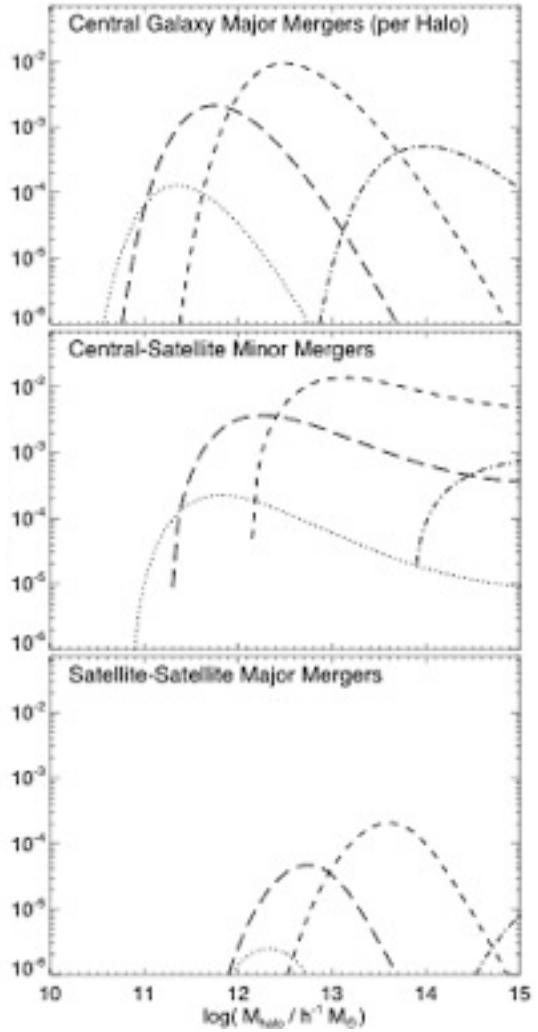
Other Fueling Mechanisms: Minor Mergers

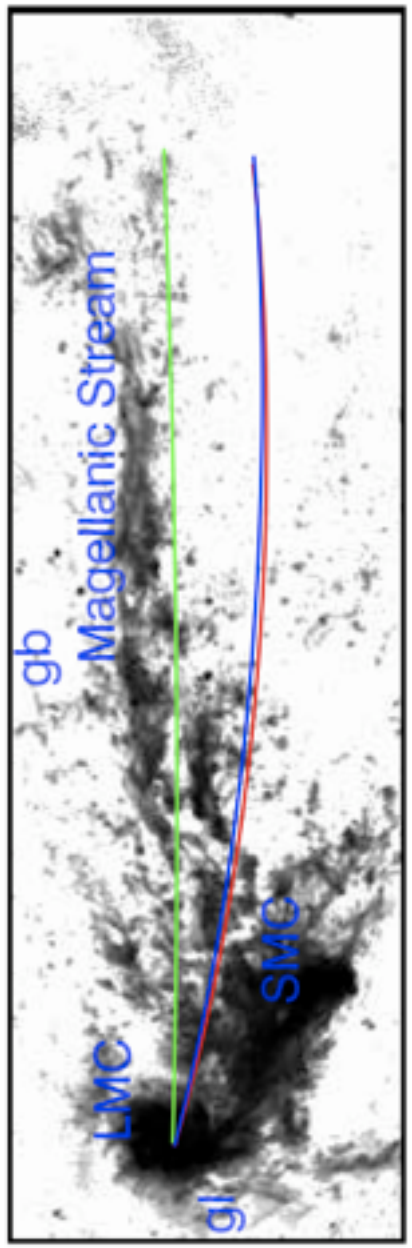
left: Projected gas density

right: Projected stellar density

XY, the orbital plane

Isolated Disk (Sbc) Galaxy
Run: execute/G3G1-u3
T.J. Cox & Patrik Jonsson, UC Santa Cruz
UC Santa Cruz, 2004

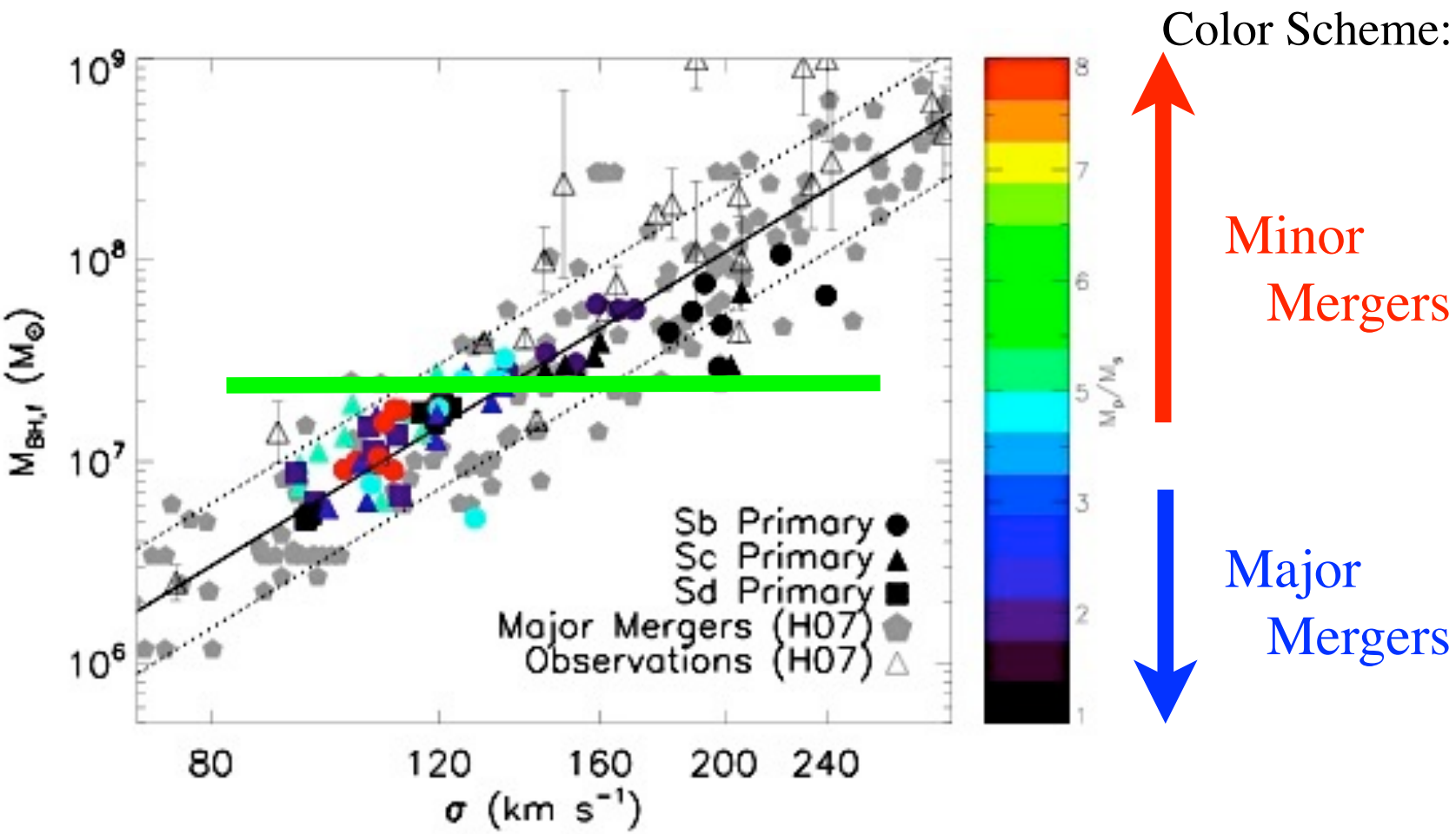




Besla et al. (2007)

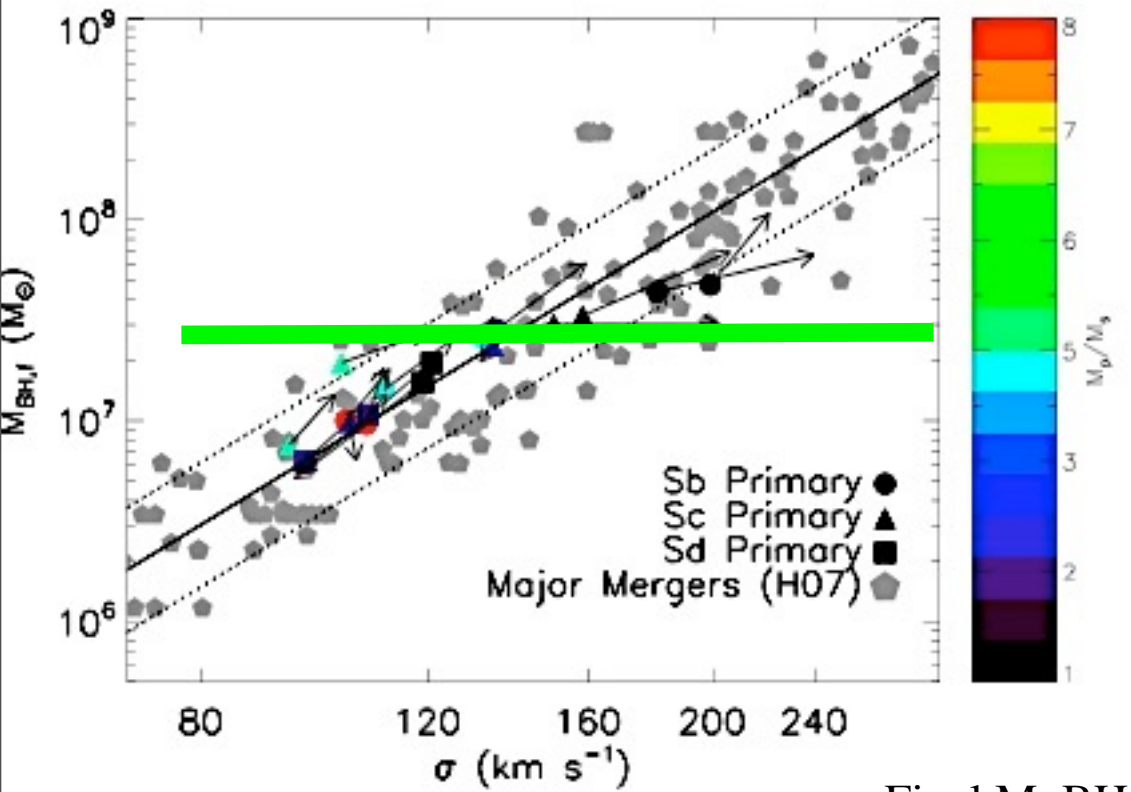
- Minor Mergers
  - Not so violent -probably don't dominate spheroid formation (LMC/SMC)
  - Not very efficient: even if growth
    ~ M_secondary/M_primary, major mergers "win"

Other Fueling Mechanisms: Minor Mergers



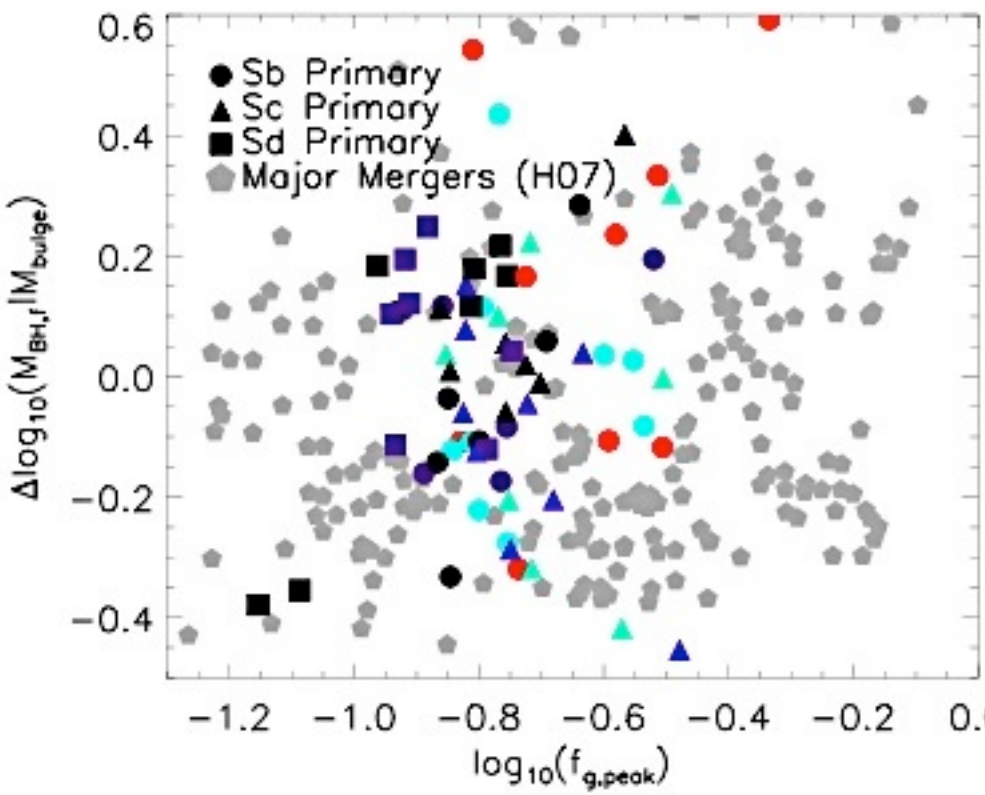
- Minor Mergers
  - Can get to ~1-2 10^7 M_sun ::: *very* hard to push beyond this

Other Fueling Mechanisms: Minor Mergers



Final M_BH relative to mean

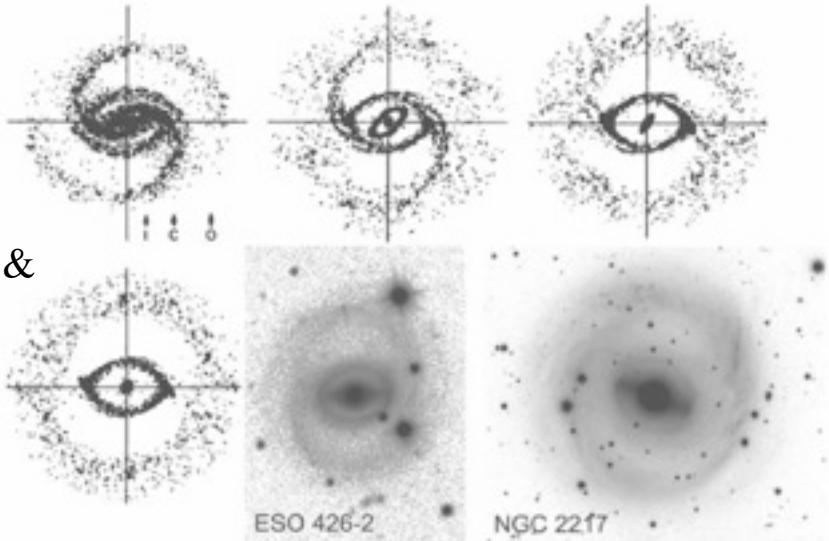
- Increase f_gas to ~0.8-1.0: *same* upper limits



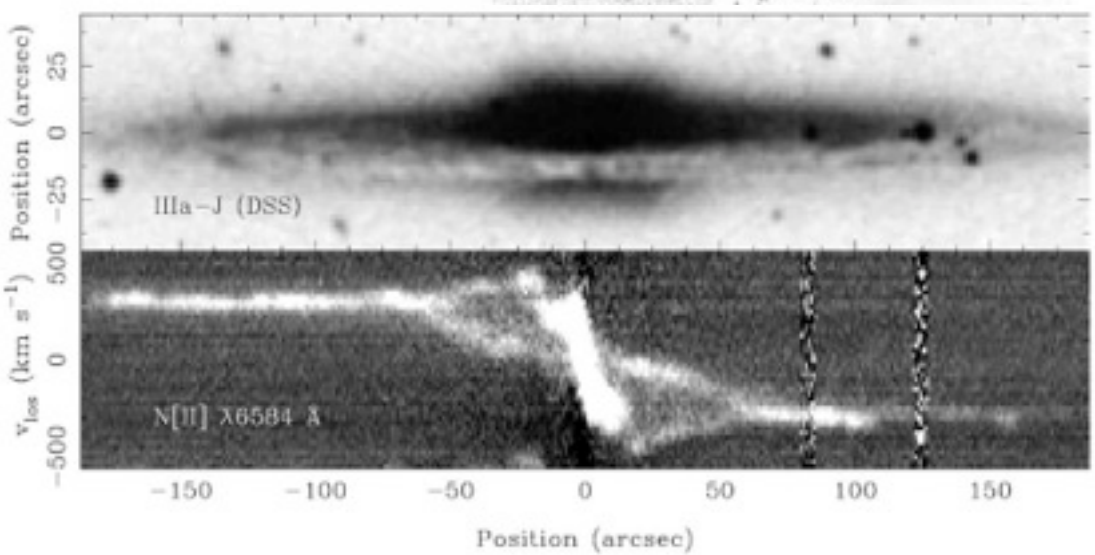
Mass of gas supplied to BH

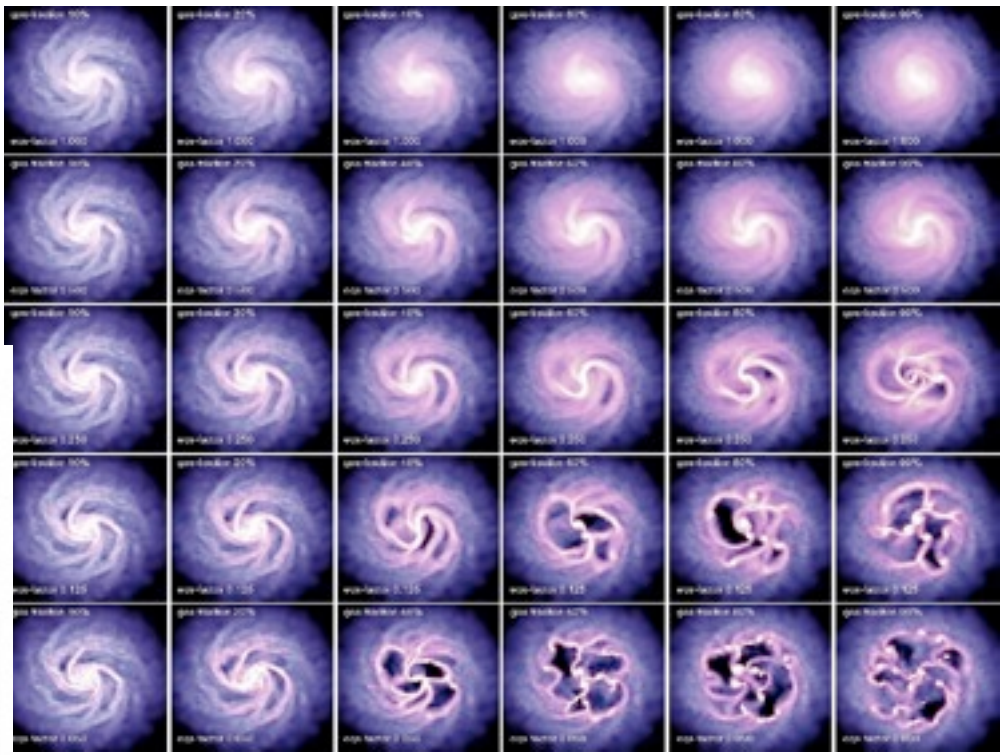
- BH doesn't care how much gas you give it:: building the potential depth is the hard part -- the BH will easily "catch up"

Other Fueling Mechanisms: Disk/Bar Instabilities



Kormendy & Kennicutt



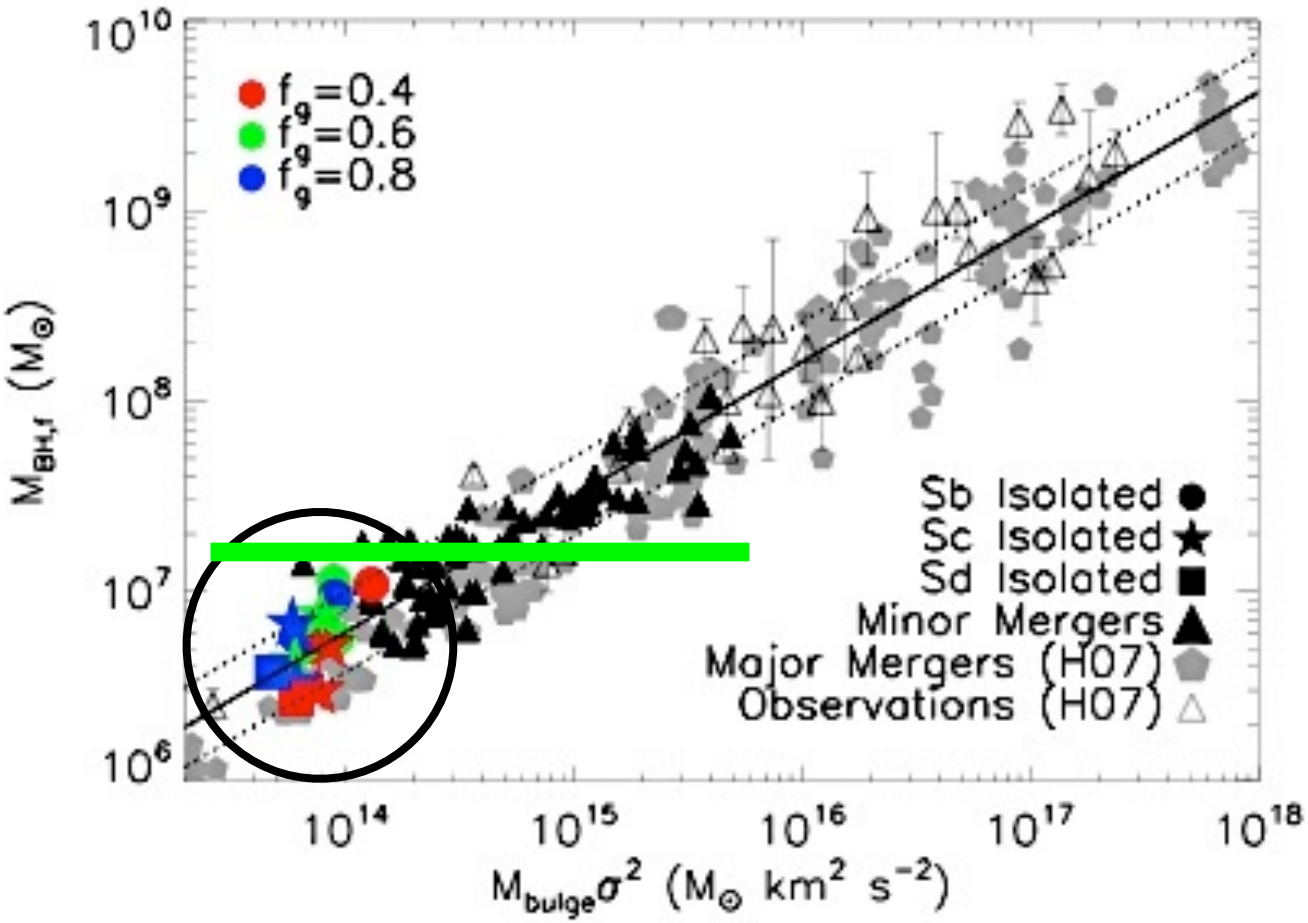


Springel et al. (2005)

- Secular Evolution/Disk Instabilities
  - Most mass in “classical” bulges, not “pseudobulges”:
    - But, *are* important below <~ Sa-types
  - Does it really solve the angular momentum problem? (Jogee et al.)

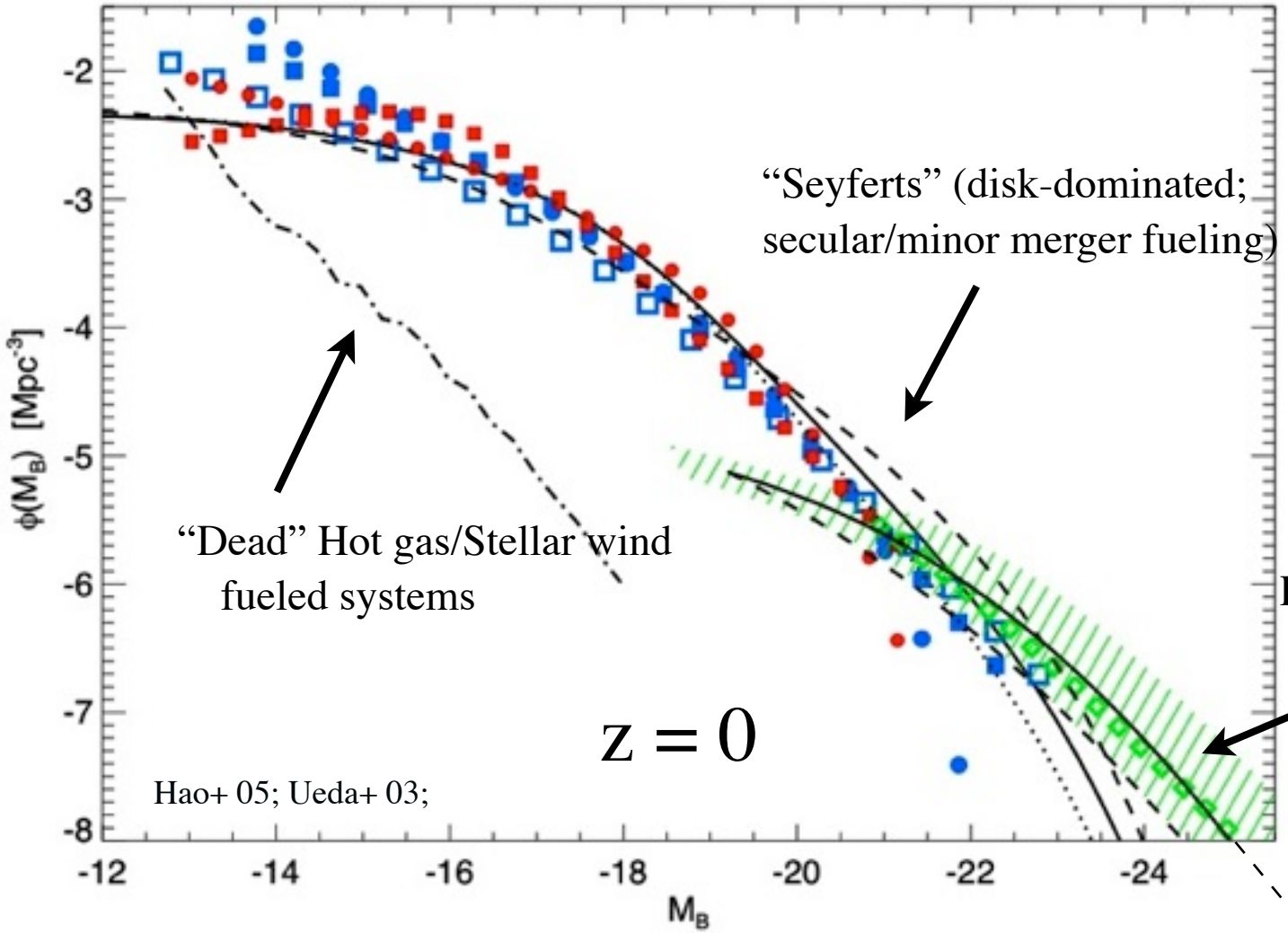
Other Fueling Mechanisms: Disk/Bar Instabilities

Bar & Toomre-unstable disk simulations:



- Same caveats as minor mergers: don't build massive bulges: doesn't matter if you can get the gas in!

Emergent Picture:



Hopkins & Hernquist 2006

"Seyferts" (disk-dominated; secular/minor merger fueling)

"Dead" Hot gas/Stellar wind fueled systems

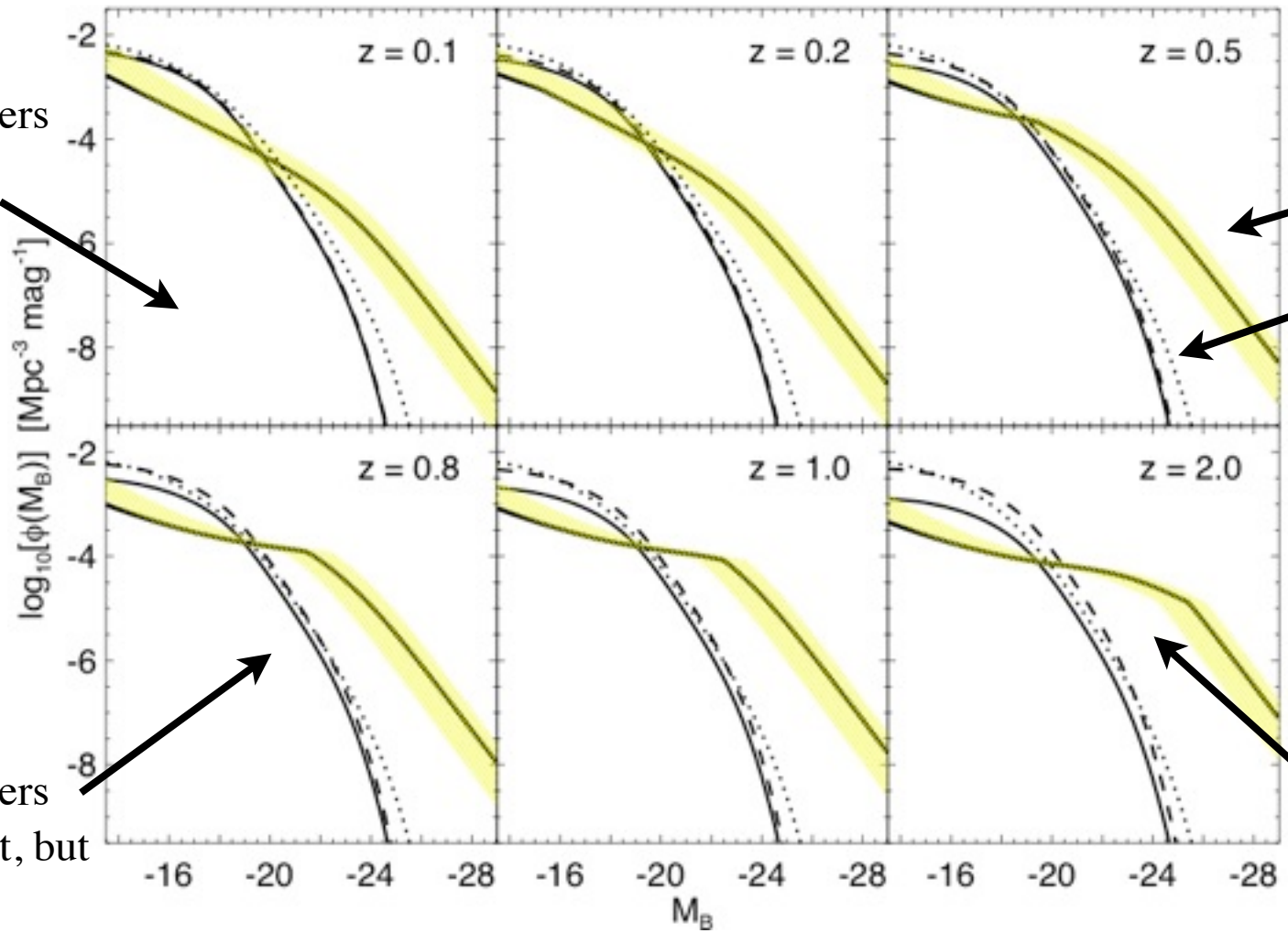
Post-Starburst Spheroids (post-merger lightcurve decay)

"Blowout" bright mergers

- Secular/Minor mergers dominate at M_B <~ -22 to -23: (L_x <~ a few 10^43)
  - Seyfert-Quasar divide is a good proxy!

Emergent Picture:

z <~ 0.5:
non-mergers
dominate



mergers

secular/quiescent

z ~ 1:
non-mergers
significant, but
sub-L*

z ~ 2-4:
non-mergers
not even *close*
to L*

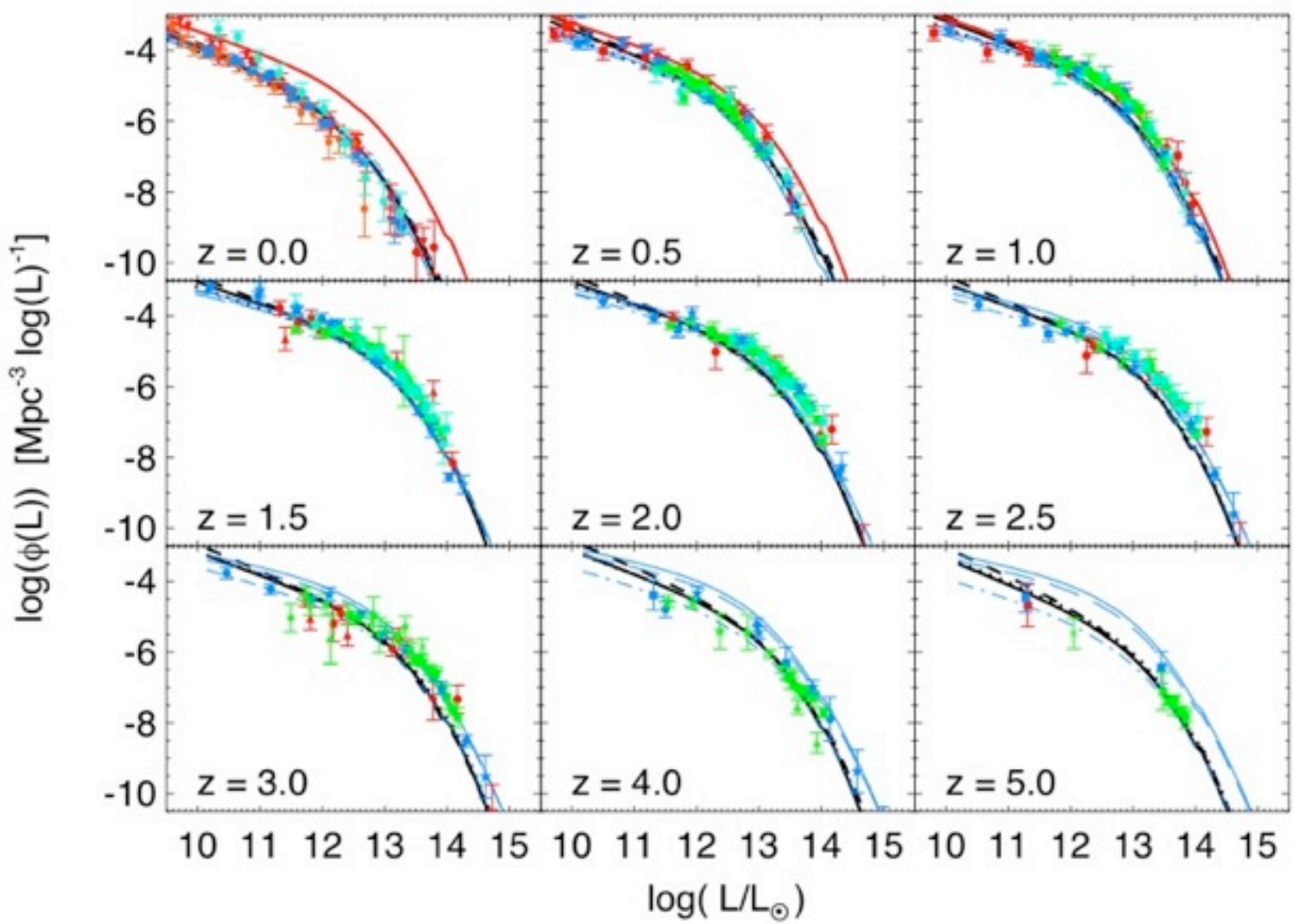
- Secular/Minor mergers dominate at M_B <~ -22 to -23:
  (L_x <~ a few 10^43)
  - Seyfert-Quasar divide is a good proxy
  - If true: they are significant (~10-20%), but not dominant contributor to total accretion density/BH mass density

Some Basic Checks:

- Construct generic model of merger-driven quasar activity (PH et al. 2007; astro-ph/0706.1243)
  - Populate halo+subhalo MFs (from cosmological simulations) with "initial" galaxies (according to HODs/ empirical constraints)
  - Let them grow (star formation & accretion)
  - Let them merge
  - Assume major, gas-rich merger > BH/bulge
  - "Paint on" detailed simulations where necessary

Predictions

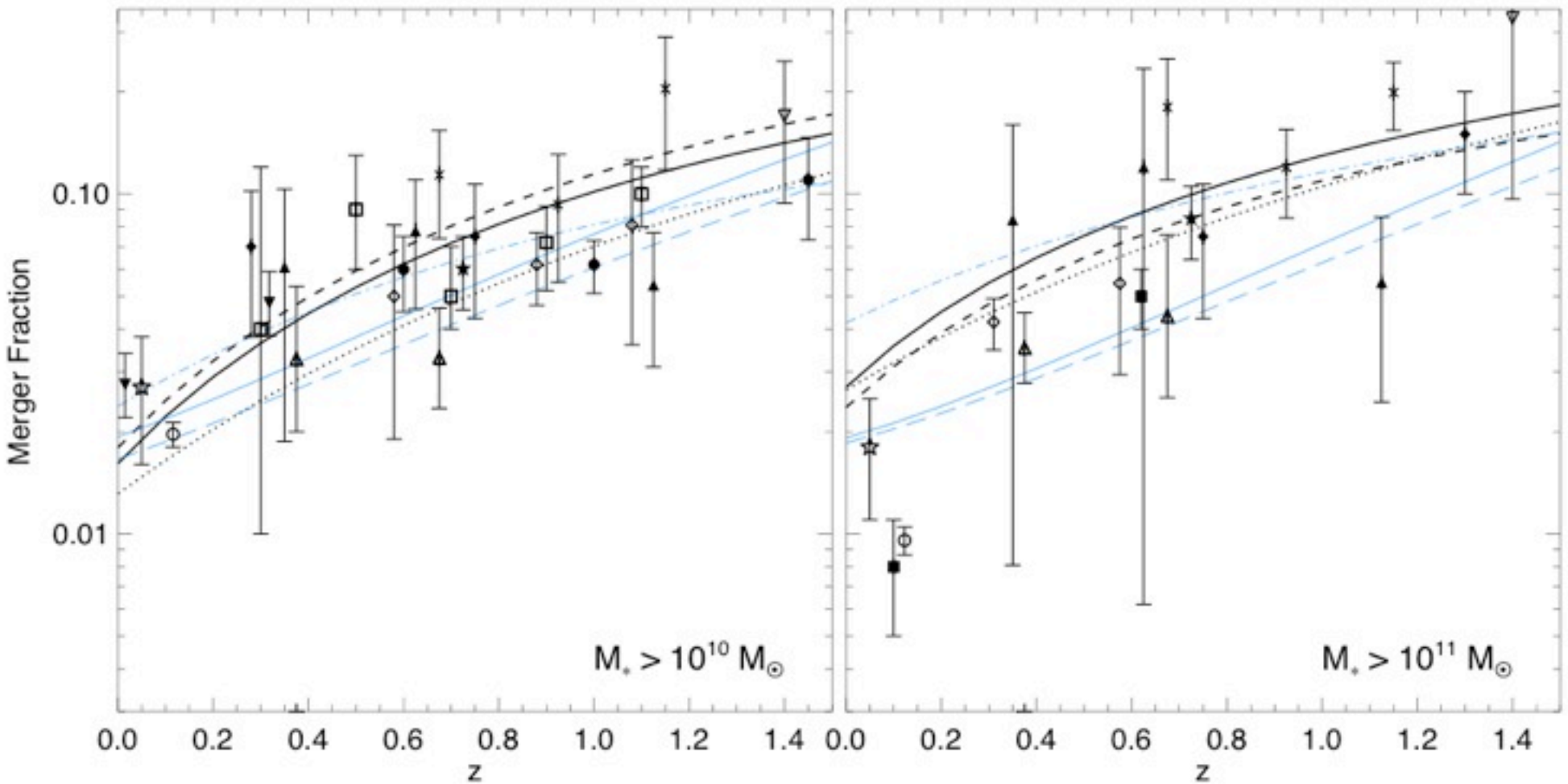
- Predicts the QLF vs. redshift, luminosity, wavelength



PH07

Predictions

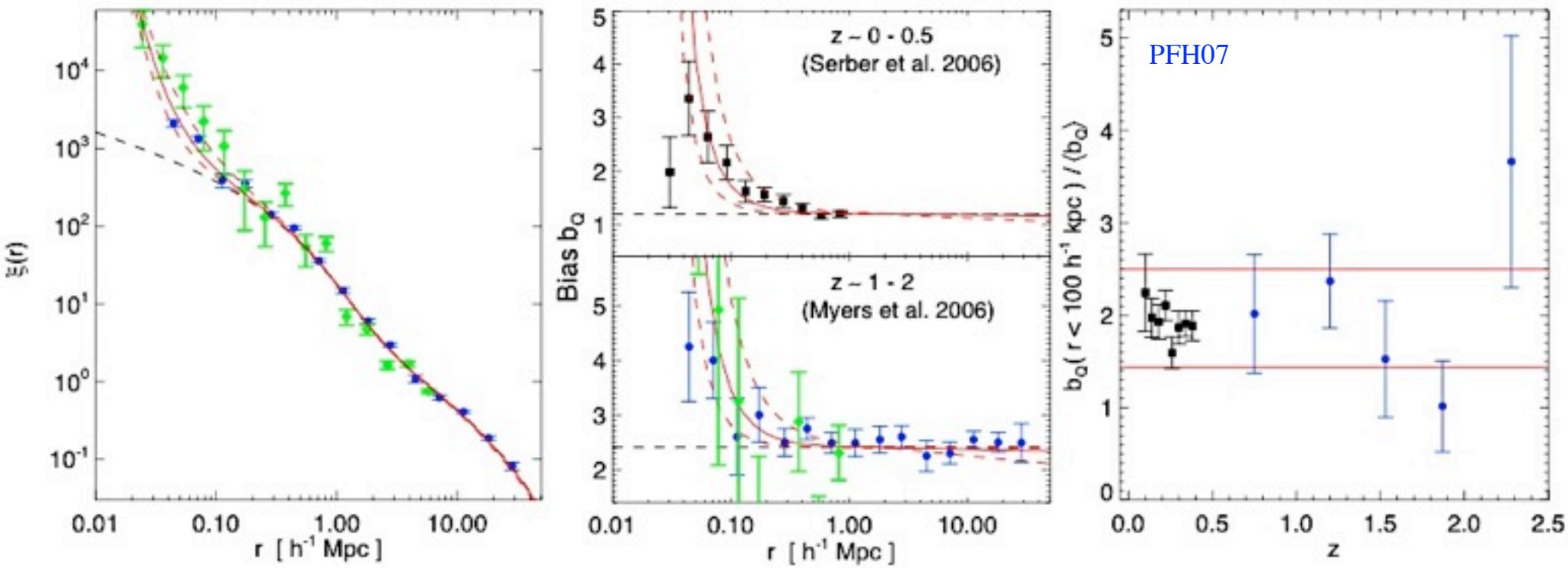
- Predicts the QLF vs. redshift, luminosity, wavelength
- There are “enough” mergers!



PH07

Where Quasars Are Born

- Observed excess of quasar clustering (quasar-galaxy and quasar-quasar pairs) on small scales, relative to "normal" galaxies with the same masses/large-intermediate scale clustering

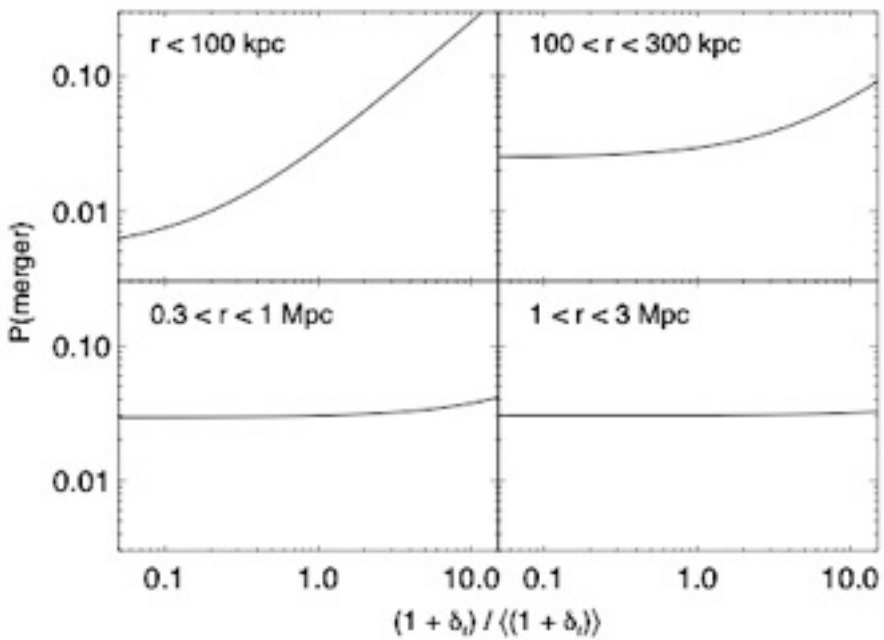


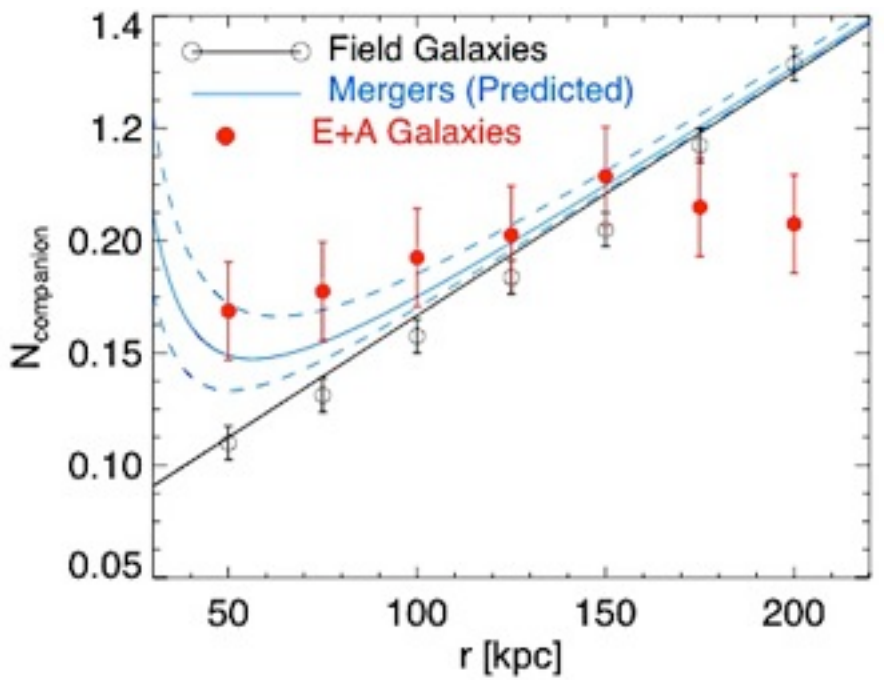
- Predicted by merger models (Thacker & Scannapieco et al., PFH)

Where Quasars Are Born

PFH07

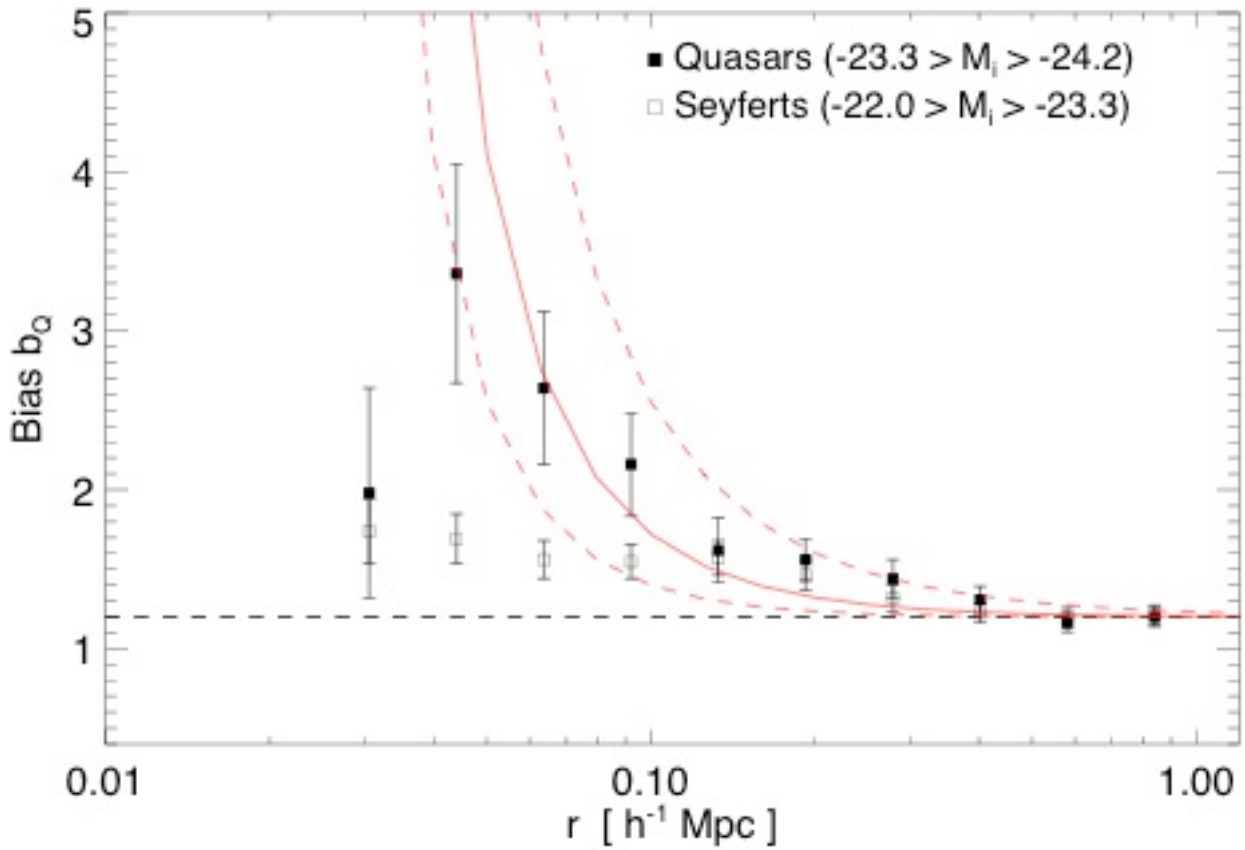
- Small-Scale Excess:
  - Predicted in merger models
    - Mergers biased to regions with *small-scale* overdensities
    - Seen in cosmological simulations (Thacker et al.)
    - Seen in merger remnants! (Goto et al.; Hogg et al.)
  - *Not* expected in secular/instability, cooling flow, stellar mass loss, or other models





Where Quasars Are Born

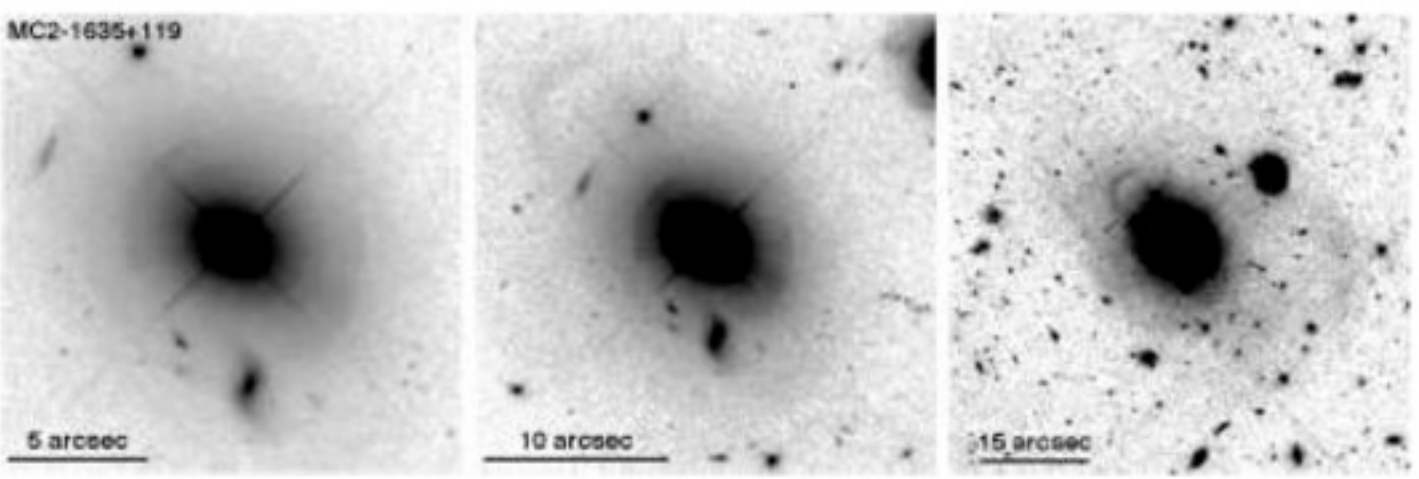
- Small-Scale Excess:
  - Not seen in Seyferts:
    - Suggests different processes dominate fueling below M_B ~ -23 (M_bh ~ 10^7)?



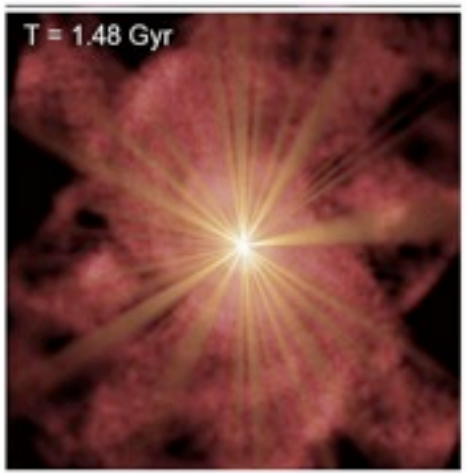
Serber et al. 2006

The Difficulty

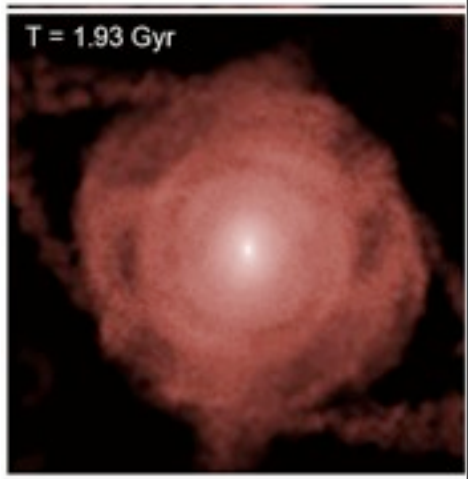
- Quasar is at the *end* of the merger
  - Host is relaxed/tidal features fade
  - SB dimming & PSF de-convolution
  - Automated routines classify even *perfect* images as “relaxed” spheroids in the quasar phase (Lotz et al.)
- Comparison samples?
  - Same *galaxy* masses (not luminosities)



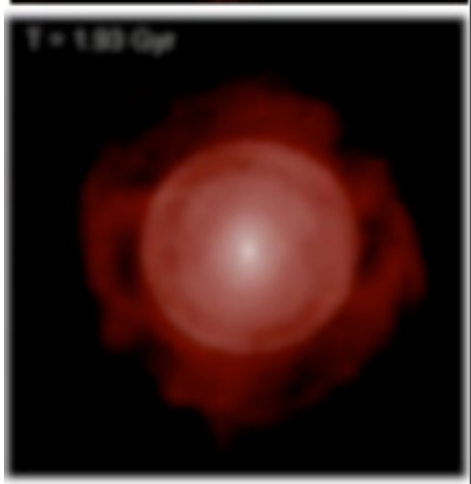
e.g. Canalizo, Bennert et al.: PG QSO Hosts



QSO = 1000xHost



QSO = Host

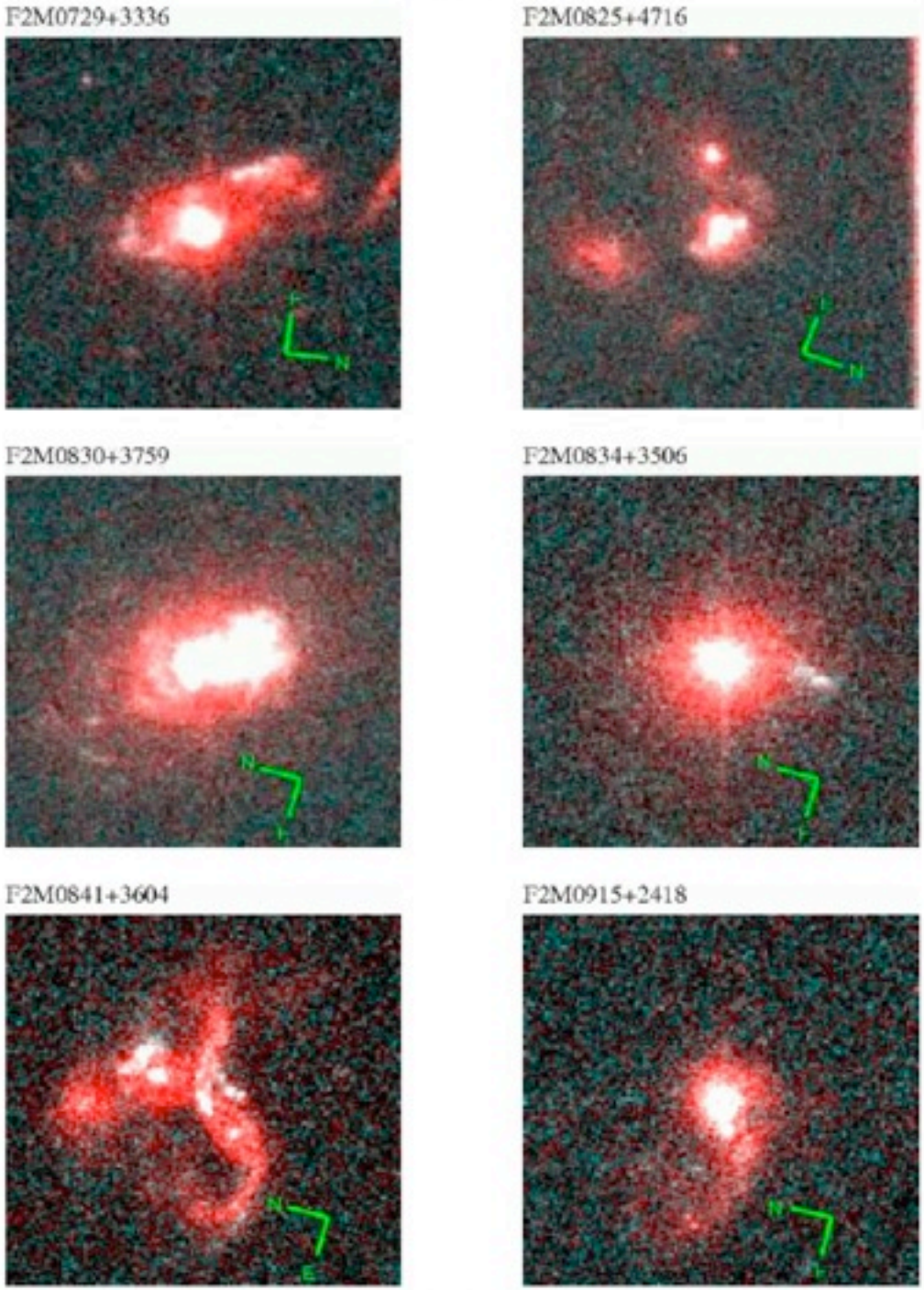


QSO = 0.1xHost

The Difficulty

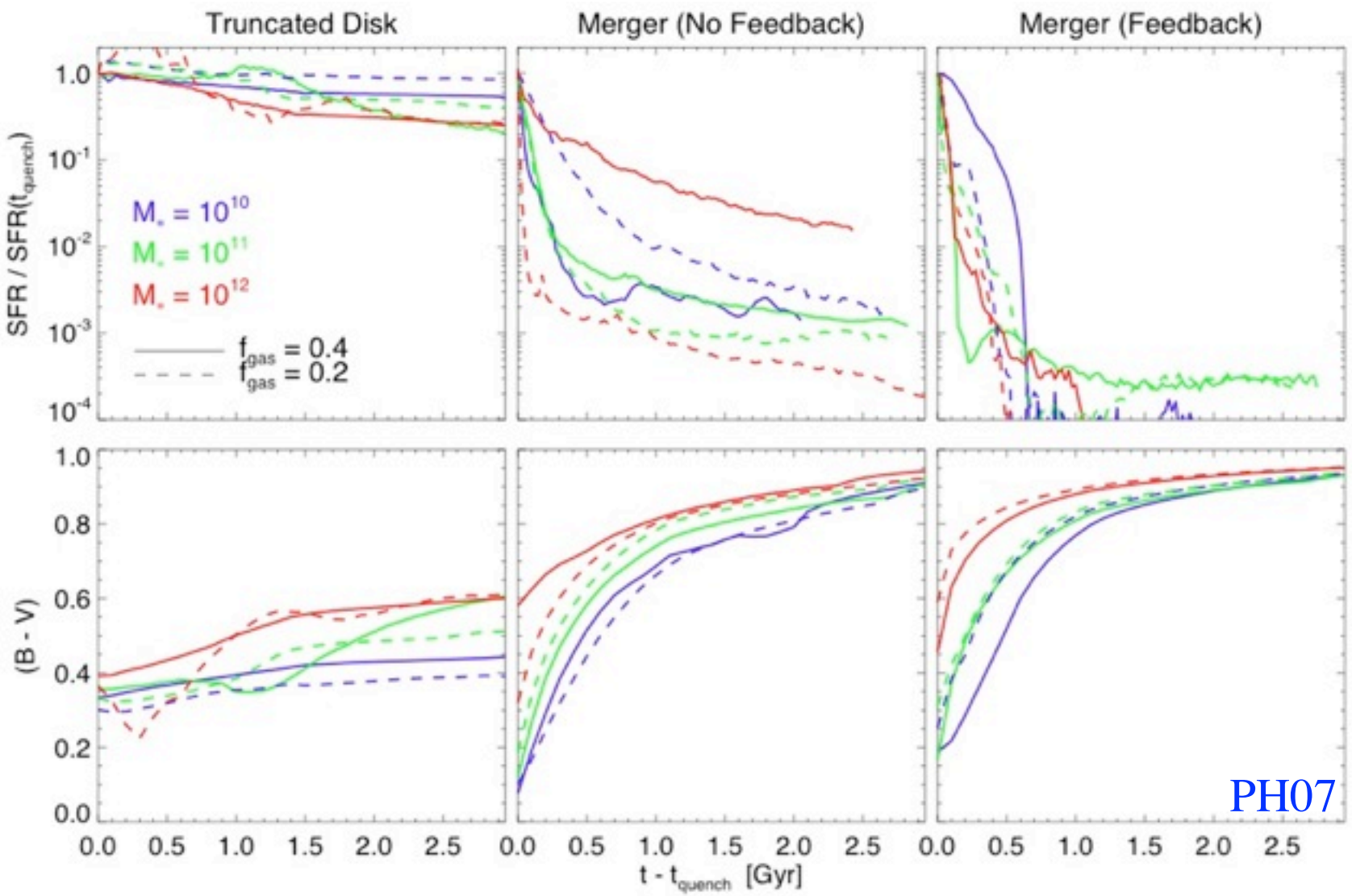
Red or IR-bright QSOs:

- Nearly ~100% mergers
  (Hutchings et al., Guyon et al., Urrutia)
- Need to prove they will turn into their bluer "cousins"



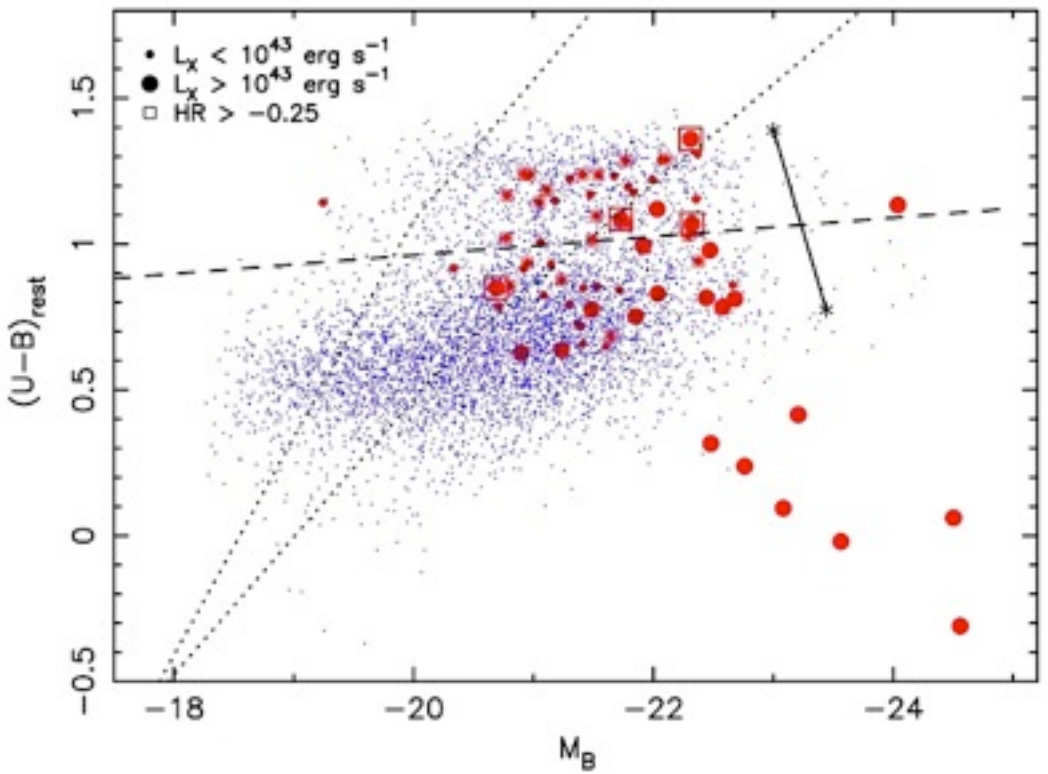
Uses of Color & Morphology Information

- Merger efficiently exhausts gas; feedback can expel what remains > remnant rapidly reddens

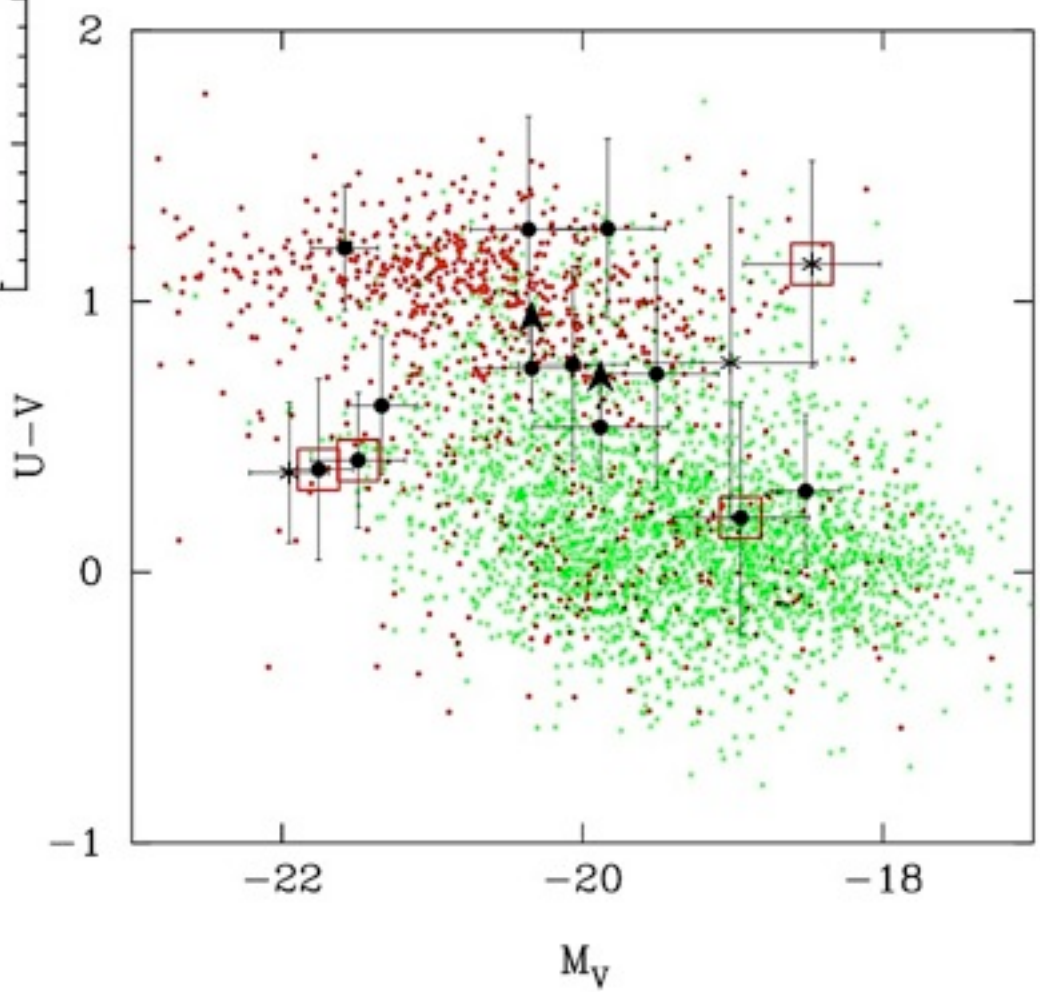


- Not true of secular evolution/pseudobulges (Kormendy, Balcells et al.)

Colors of Quasar Hosts



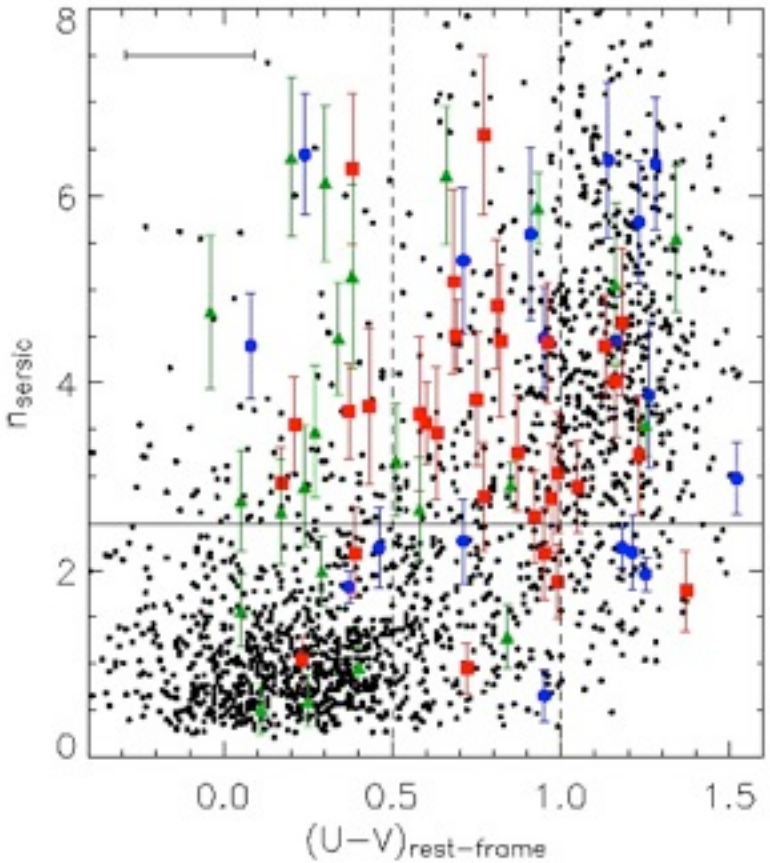
Nandra+ ‘06
DEEP2
0.7 < z < 1.4
X-ray QSOs



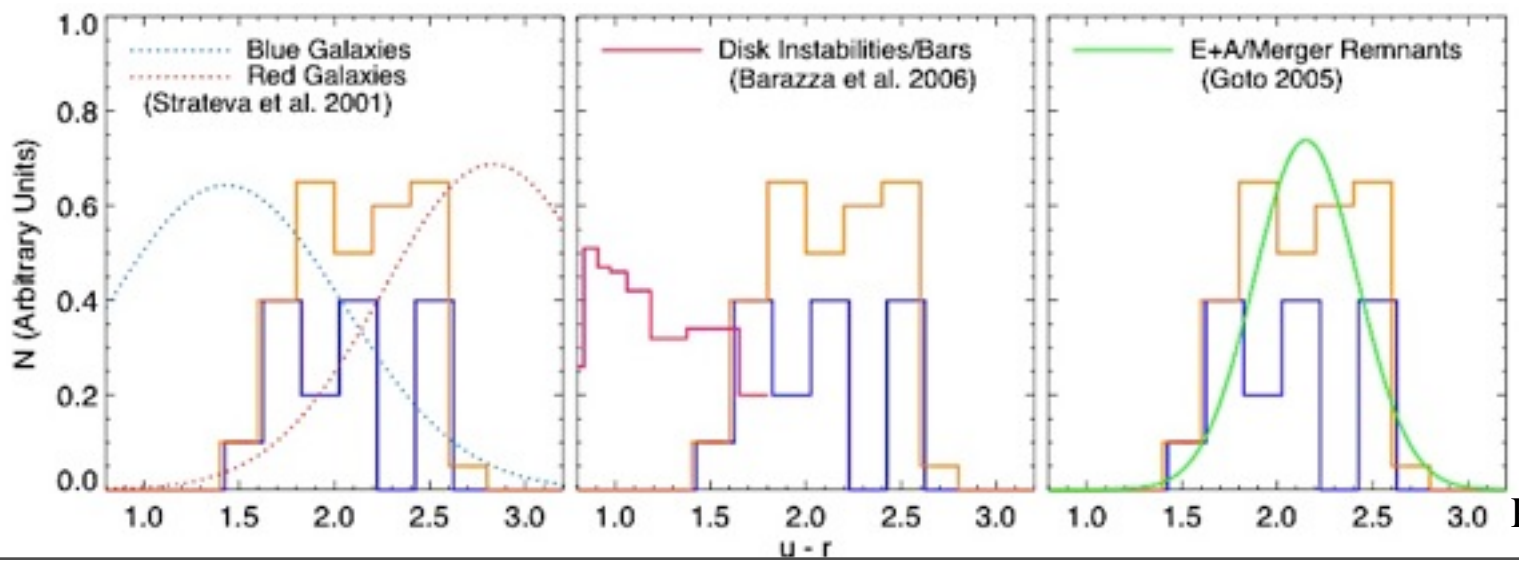
Sanchez+ ‘05
GEMS
0.5 < z < 1.1
Optical QSOs

Color & Morphology of Quasar Hosts

- Quasars live in *blue spheroids*
- Need to go to next level: full stellar populations - are these really post-SB?
- Examine the time/redshift dependence



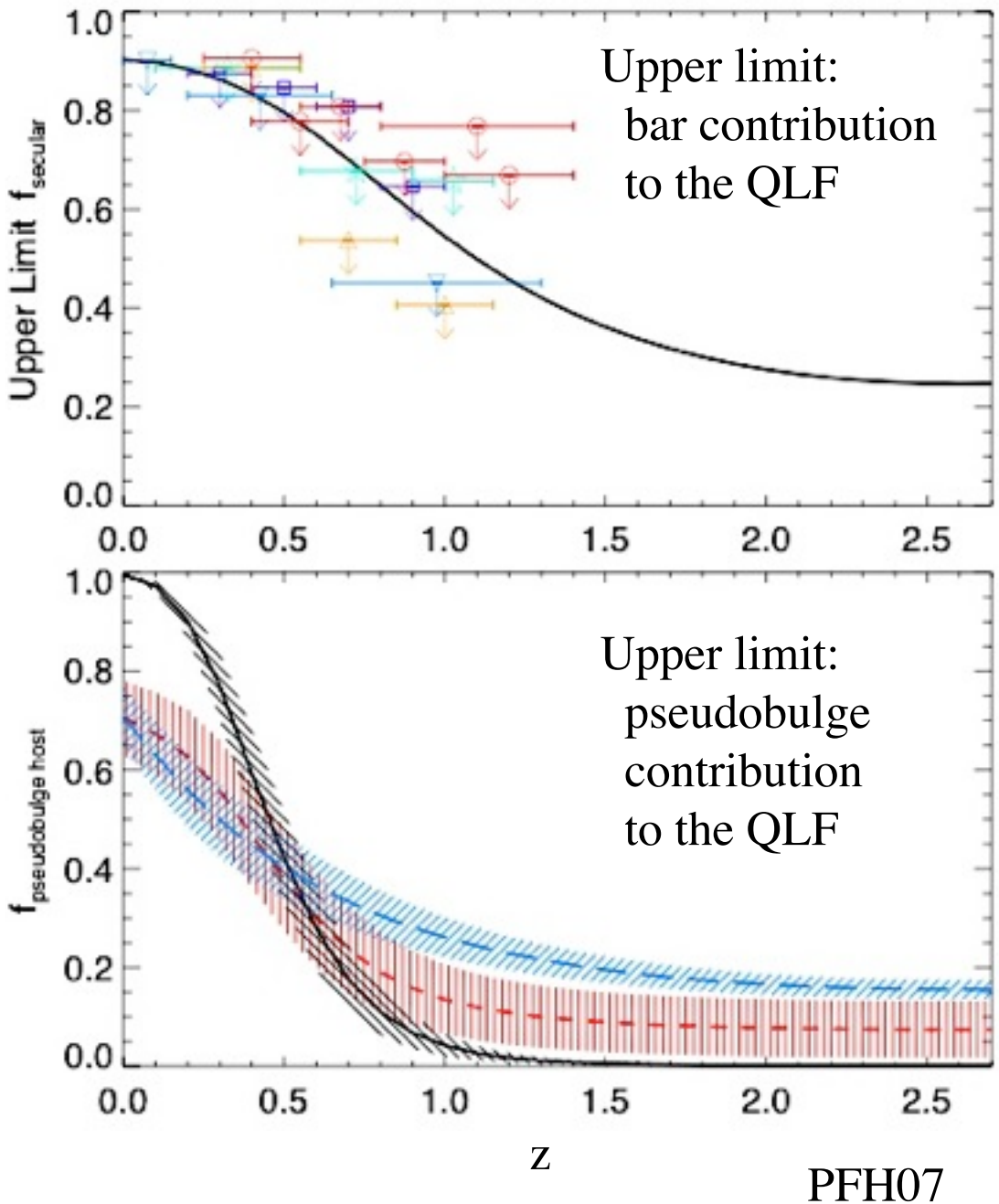
Silverman et al.



PH07

Morphology of Quasar Hosts

- Mergers form "classical" bulges; secular evolution forms "pseudobulges"
- Pseudobulges important only in relatively late-type galaxies; small M_bh
- Bar fraction & pseudobulge fraction ~constant to z~1-2



PFH07

Summary

- M_BH traces spheroid E_binding
  - Further suggests *self-regulated* BH growth

- In feedback-regulated growth models, getting fuel to the BH is the *easy* part
  - Need to *build up the central potential* or the BH will just blow out any new gas

- "Are AGN mergers?" is the *wrong* question: we should ask:
  - "Where (as a function of L, z, d) do mergers vs. secular processes dominate the AGN population?"
    - Clustering vs. scale
    - Host galaxy colors/SFH
    - Host morphology/kinematics
      - Both "merger signatures" and e.g. disk vs. elliptical, pseudobulge vs. classical bulge