A Unified, Merger-Driven Model for the Origin of Starbursts, Quasars, the Cosmic X-Ray Background, Supermassive Black Holes and Galaxy Spheroids

The Implications of Realistic Quasar Evolution

(Di Matteo, Springel, & Hernquist 2005)

Philip Hopkins 05/25/05

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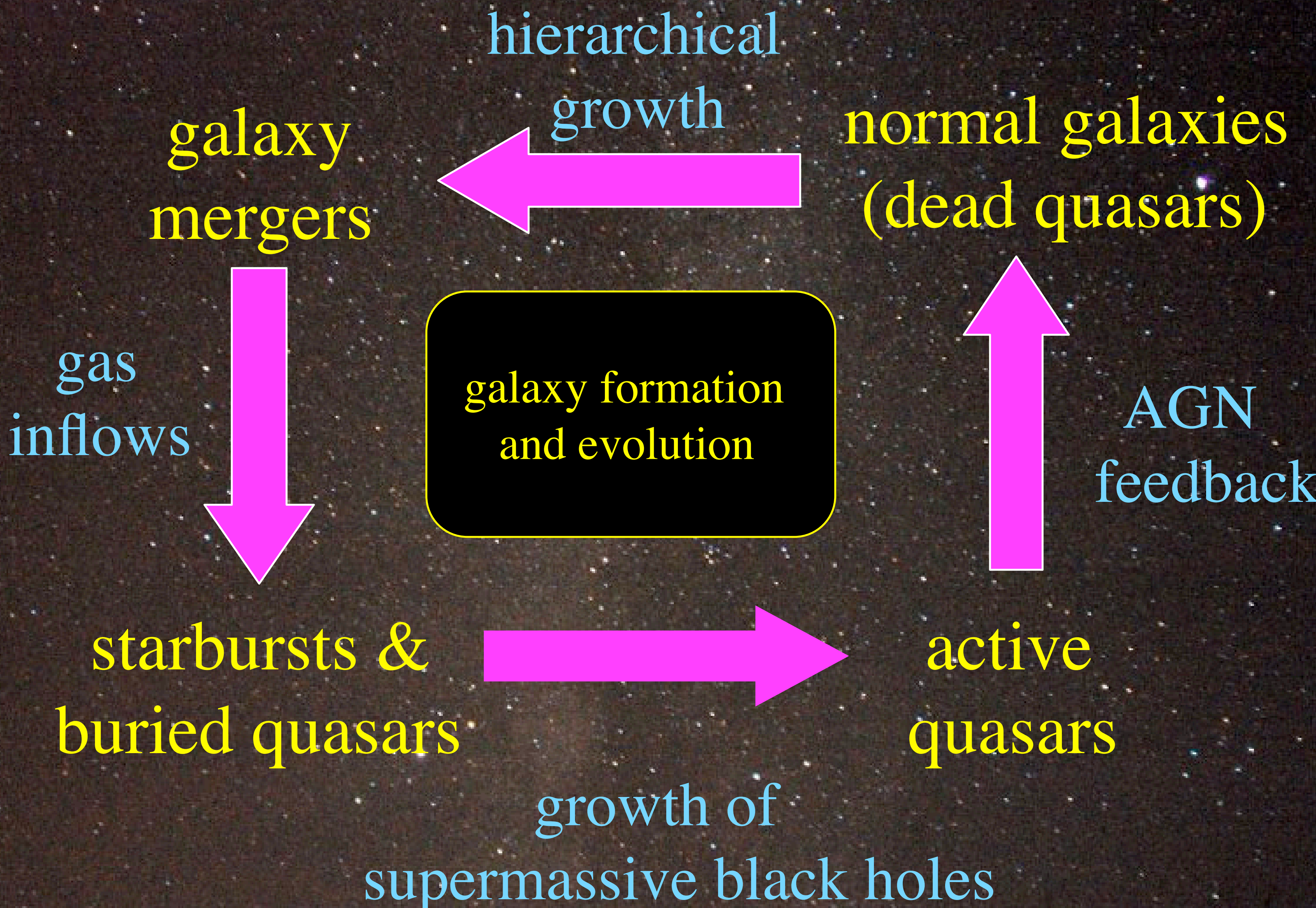
Outline

- Overview -
  - What's the big picture?
  - How can we study it?
- Quasar Lifetimes & the Luminosity Function
  - Calculating the quasar lifetime
  - Why does it matter?
- Quasar Obscuration
  - Evolution vs. static structures
- The Consequences
  - Suddenly, everything falls into place…

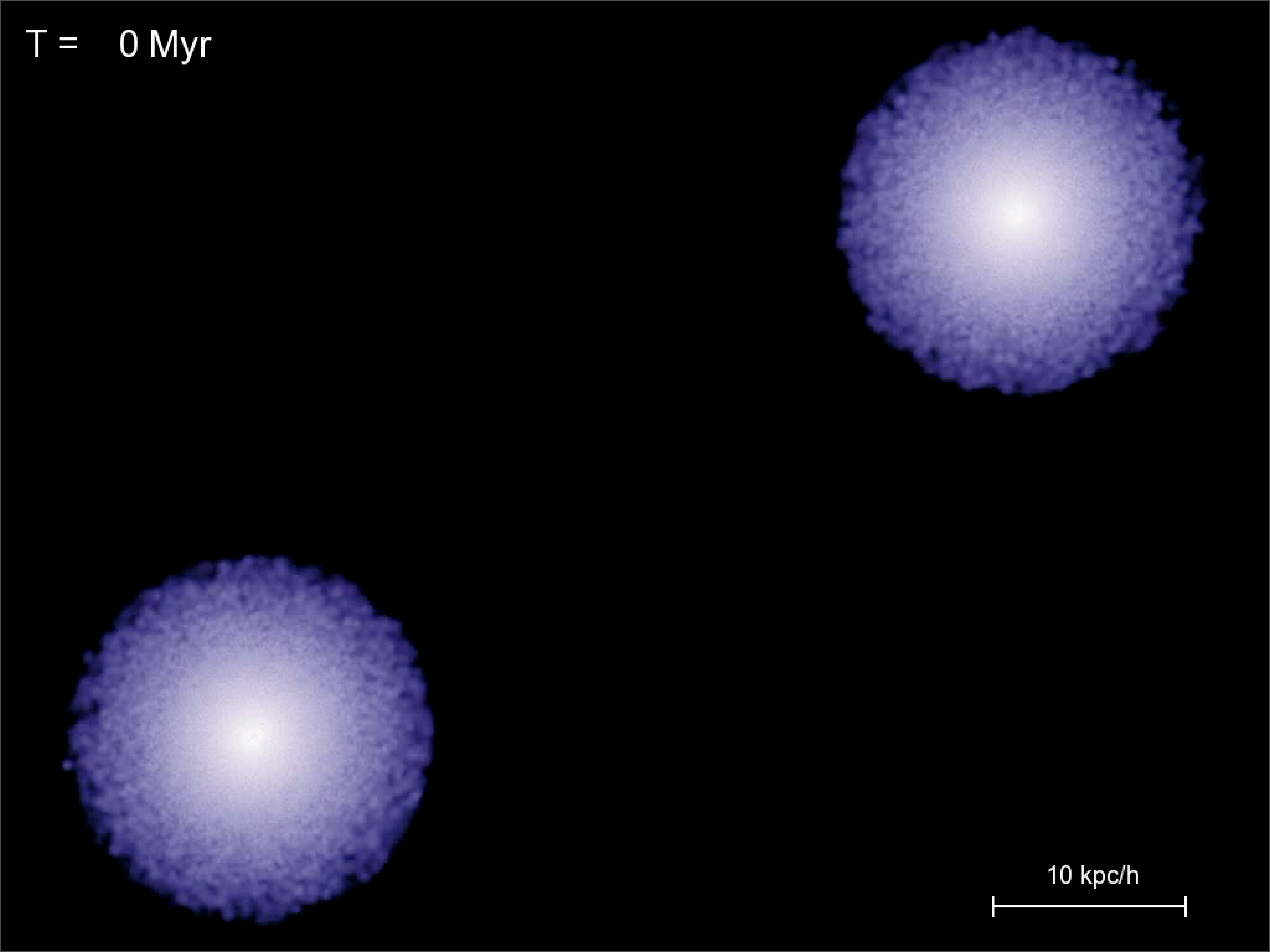
"Cosmic Cycle" for Galaxy Evolution



How to study?

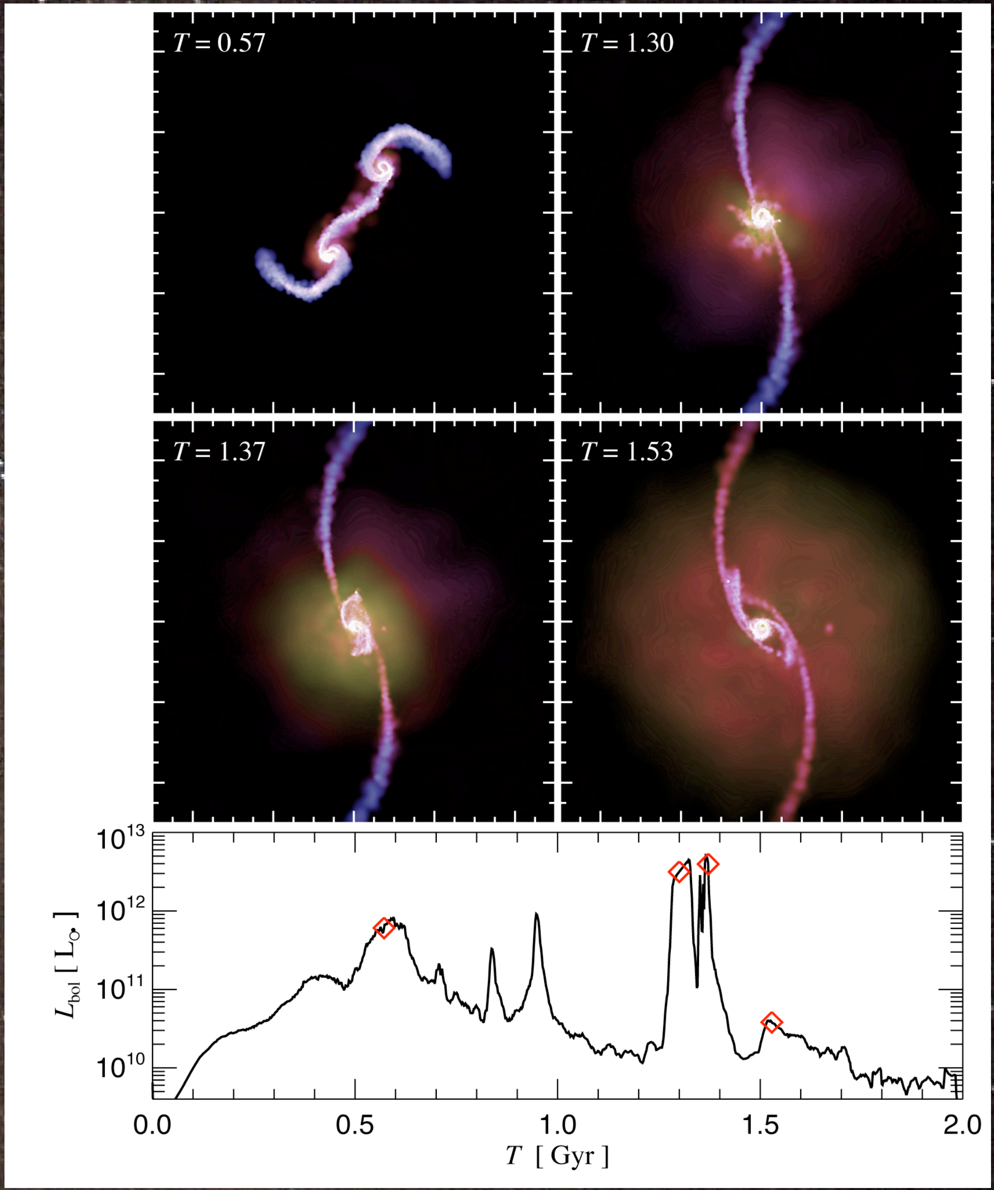
Need to turn to simulations to describe dynamics:

- GADGET-2 code: incorporates BH growth (Springel et al. 2005b)
  - Eddington-limited Bondi-Hoyle accretion
  - Feedback to surrounding ISM: ~5% of energy couples thermally
- Multi-phase ISM for star formation, (Springel & Hernquist 2003)
  - Variable pressurization/equation of state (Springel et al. 2005)
- Simulations of major galaxy mergers:
  - Torquing -> central gas & starbursts (e.g., Hernquist 1989, Barnes & Hernquist 1991, 1996, Mihos & Hernquist 1994, 1996)
  - Gives M-sigma relation (Di Matteo et al. 2005)

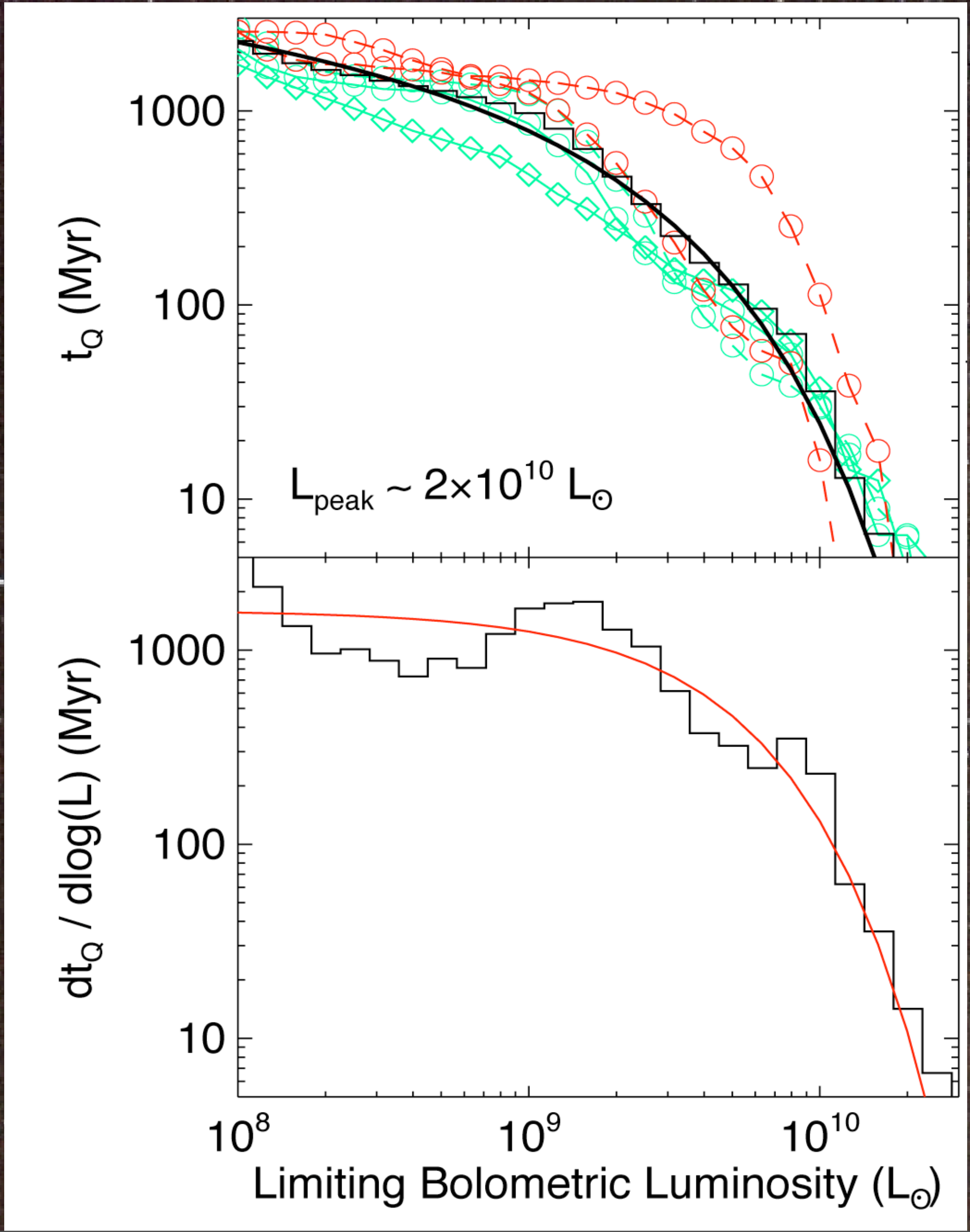

T = 0 Myr
10 kpc/h

Light Curves and Lifetimes

- Complicated light curve
- Column densities evolving
- Obscured growth vs. "blowout" phase



Lifetimes: Not a Light Bulb!



- Look at the time the simulations spend in each luminosity interval
- Not a delta function
- Not exponential growth
- More time at low luminosities than previously assumed
- LUMINOSITY-DEPENDENT lifetimes

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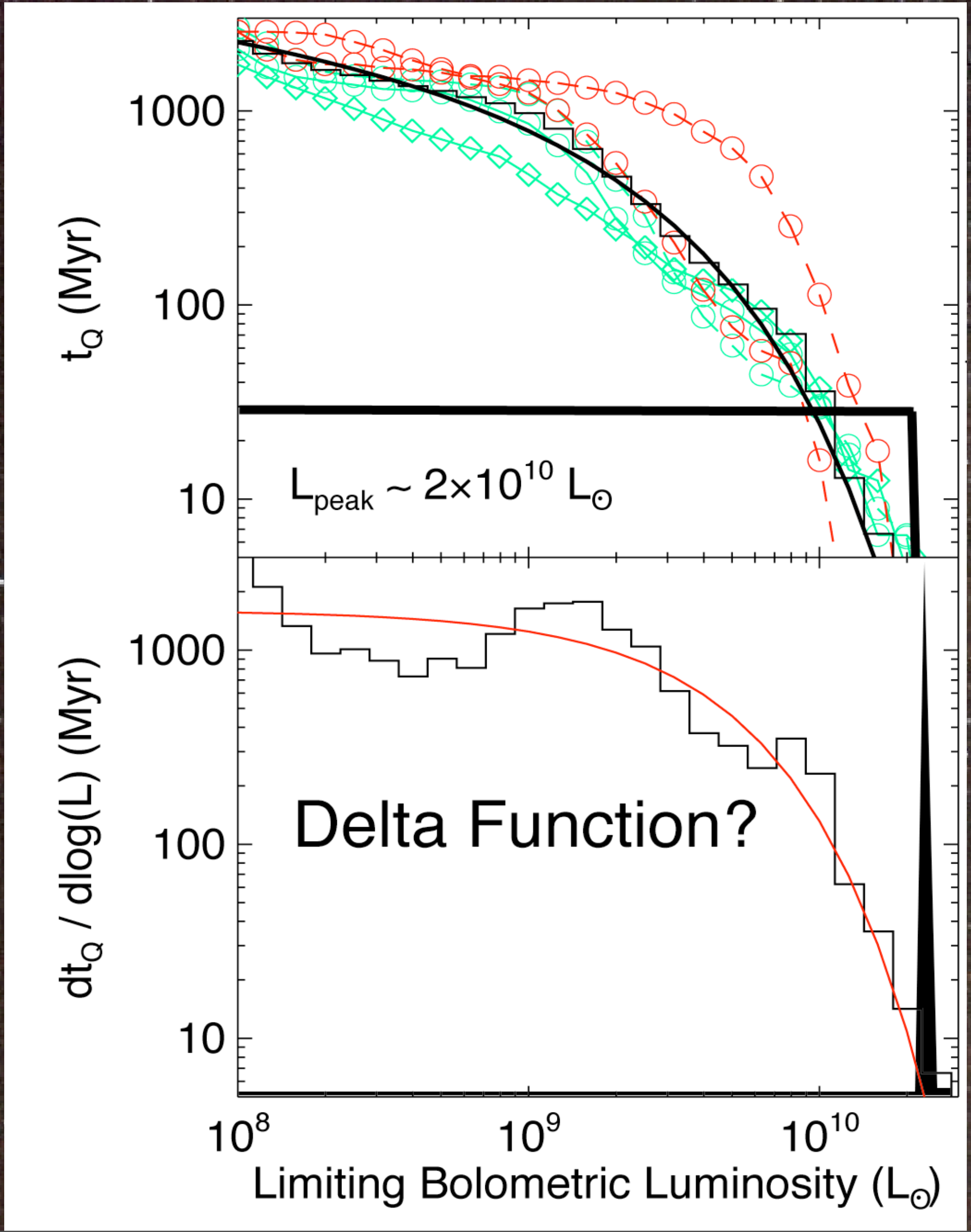

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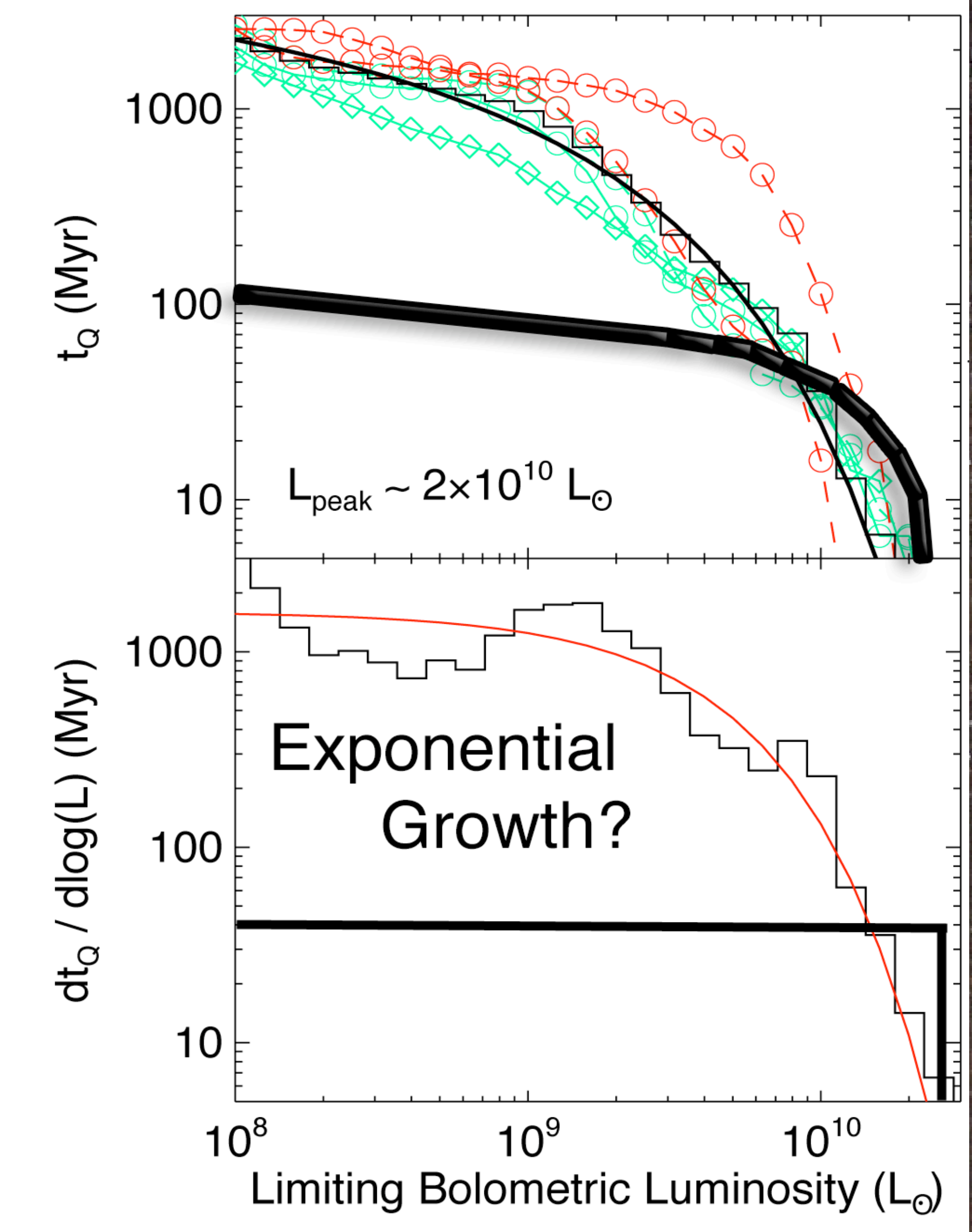

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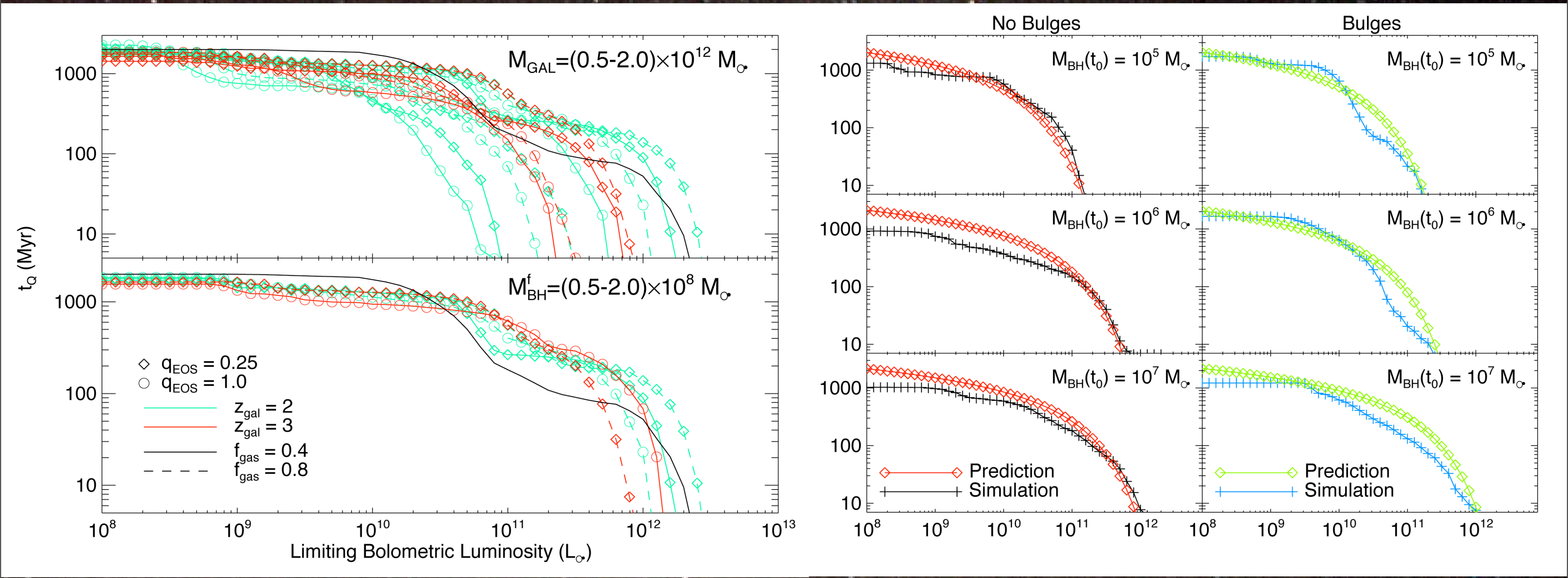
Robustness of Quasar Lifetimes



- As a function of *peak* luminosity (*final* black hole mass), the lifetime is extremely robust. Even if we vary:
  - Redshift (Z = 0 - 6)
  - Initial BH mass
  - Gas fractions
  - Orbital / merger parameters
  - Virial velocity 50-500 km/s
  - Host structure (bulge / no bulge)
  - Gas equations of state / star formation

Why Do We Care?

- X-ray and IR backgrounds
  - Different spectral shape
- Reionization
  - Stromgren sphere structure (Wyithe & Loeb 2004, Adelberger 2004)
- Host properties (morphologies, etc.)
- Non-trivial luminosity-black hole mass relations
- Continuous connections of low-high luminosity objects?

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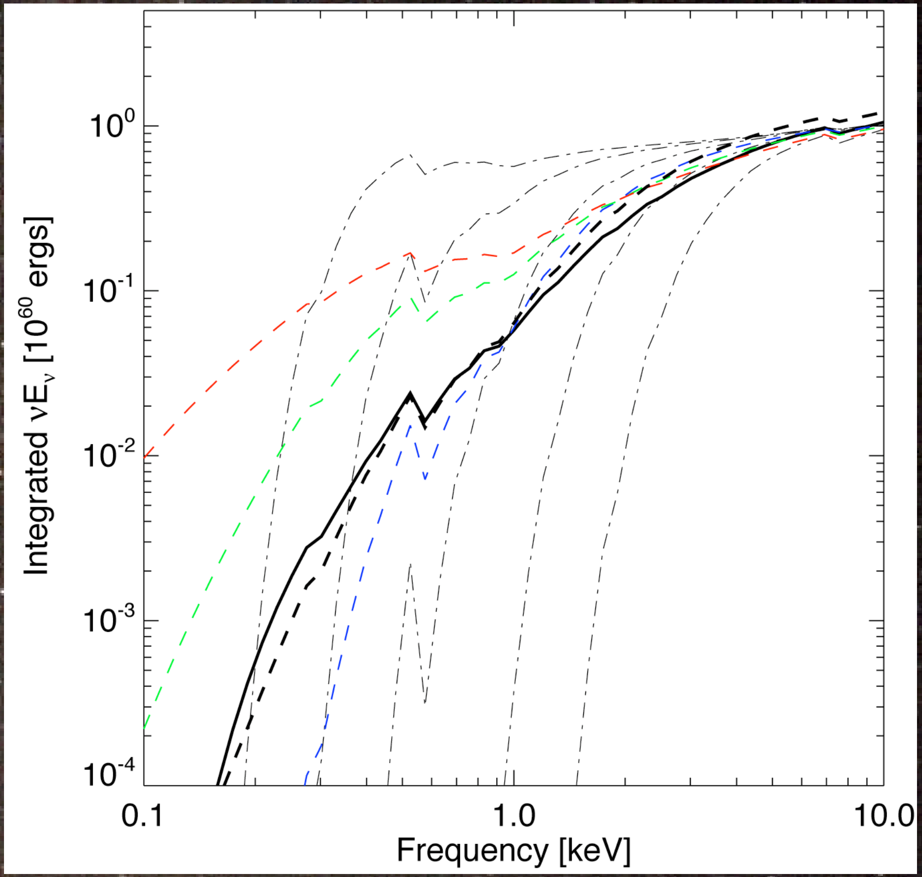

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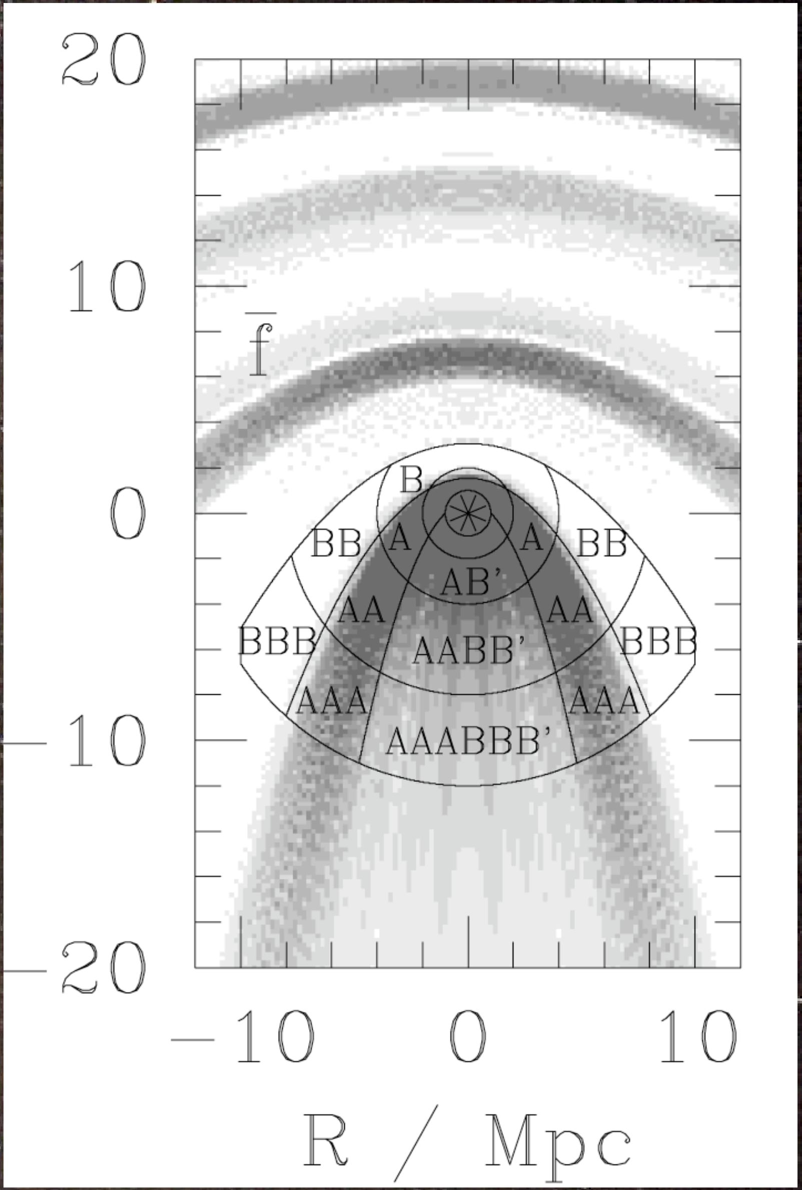

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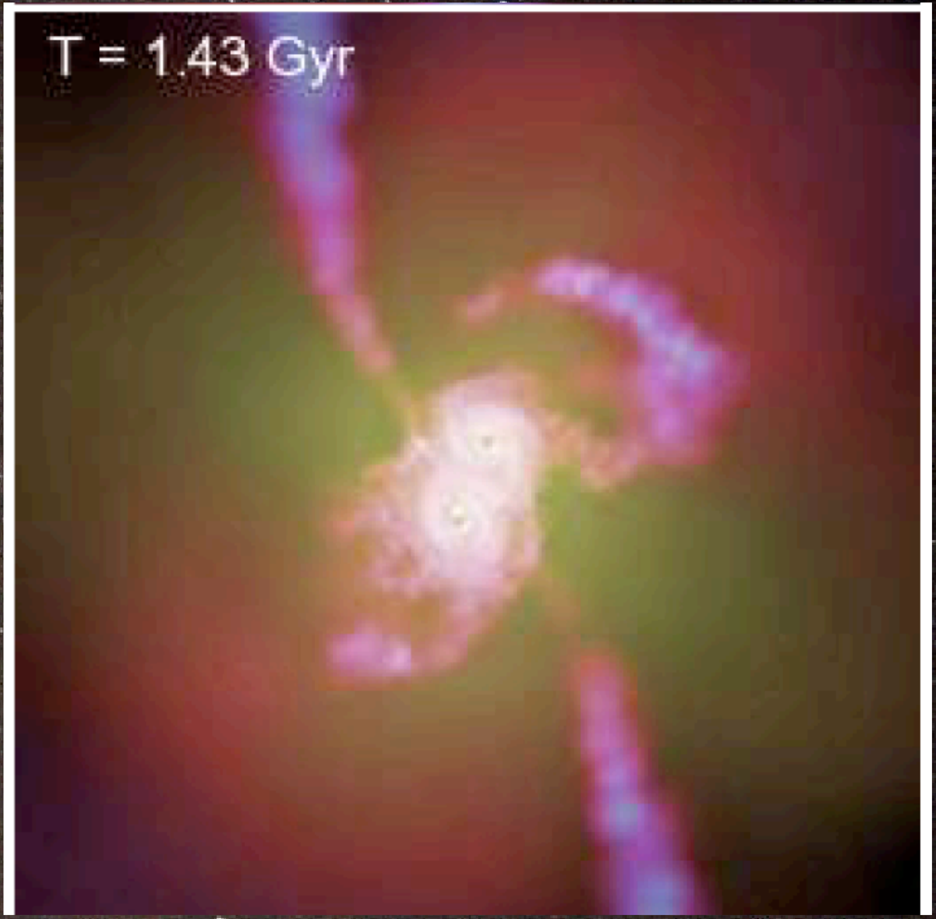
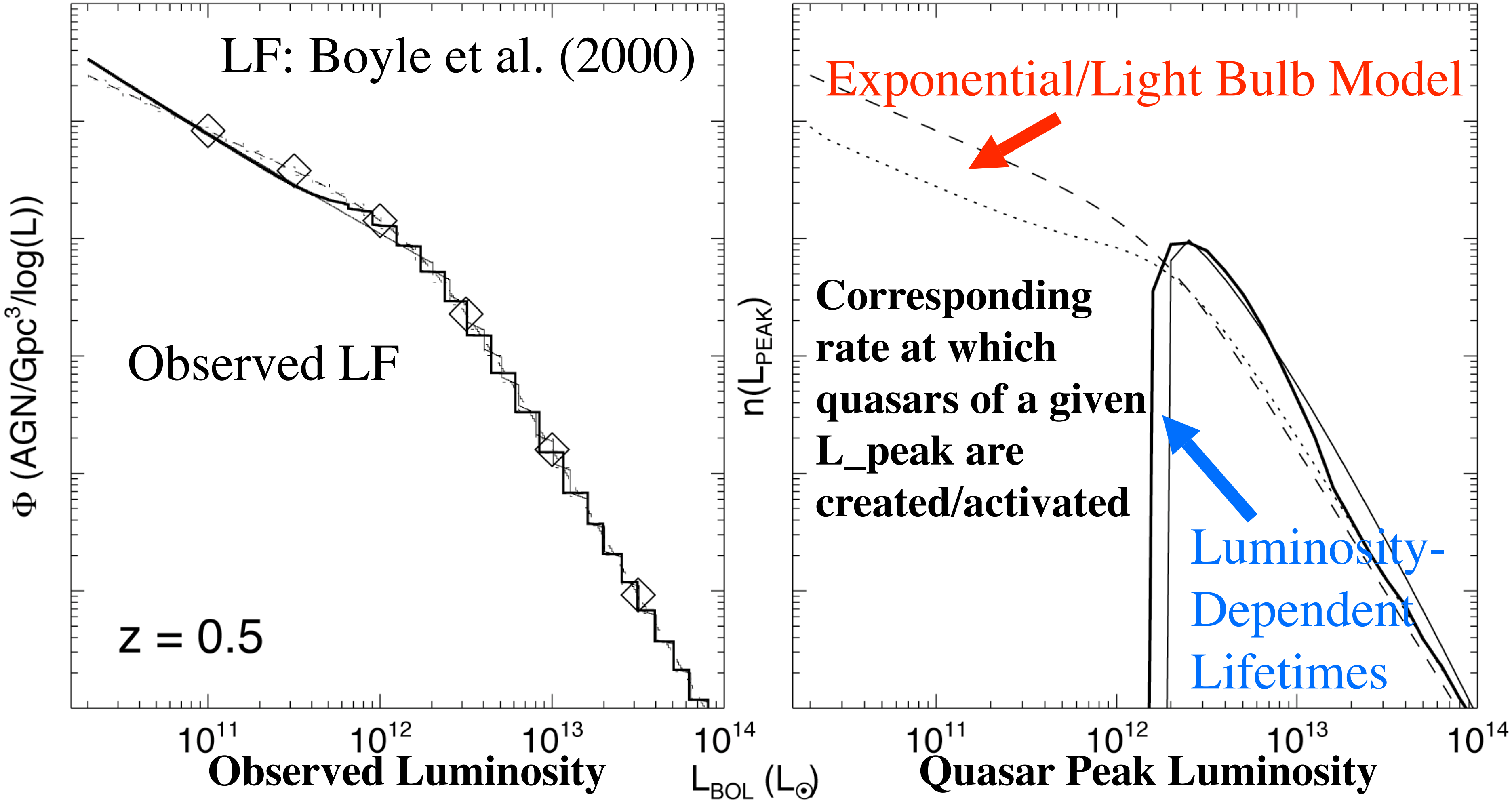


The Luminosity Function

Luminosity Dependent lifetimes demand a completely new interpretation of the quasar luminosity function



The Luminosity Function: A New Interpretation

- Steep end traces sources near peak luminosity, as previously assumed
- Faint, shallow end is dominated by sources with peak luminosity near the break

Implications (just a subset):

SMBH density & distribution

Quasar clustering/correlations

Eddington ratio distributions

Background intensities

Quasar-host galaxy correlations

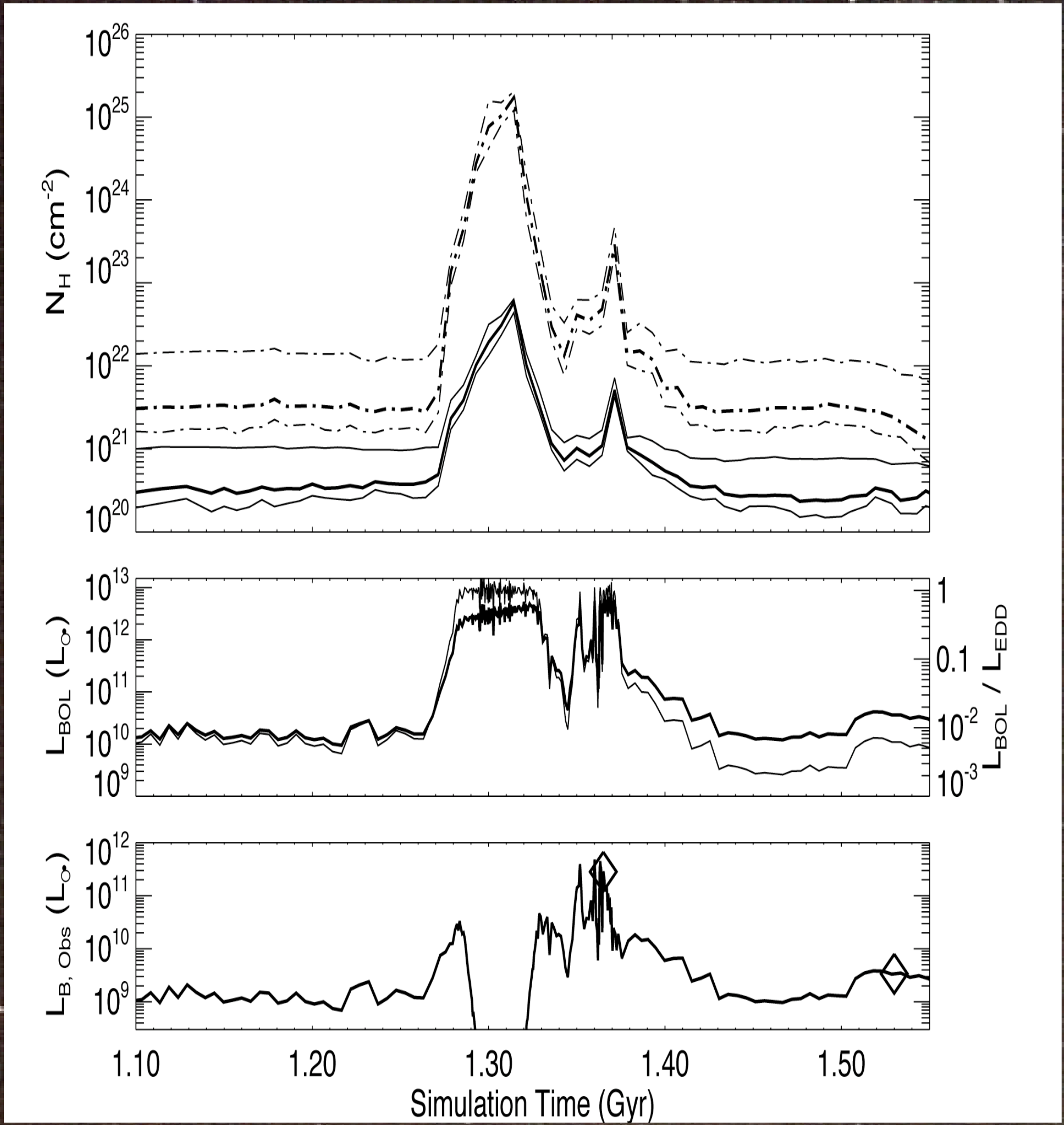
Active black hole masses

Evolution of L_break, M_QSO

High-z radio sources

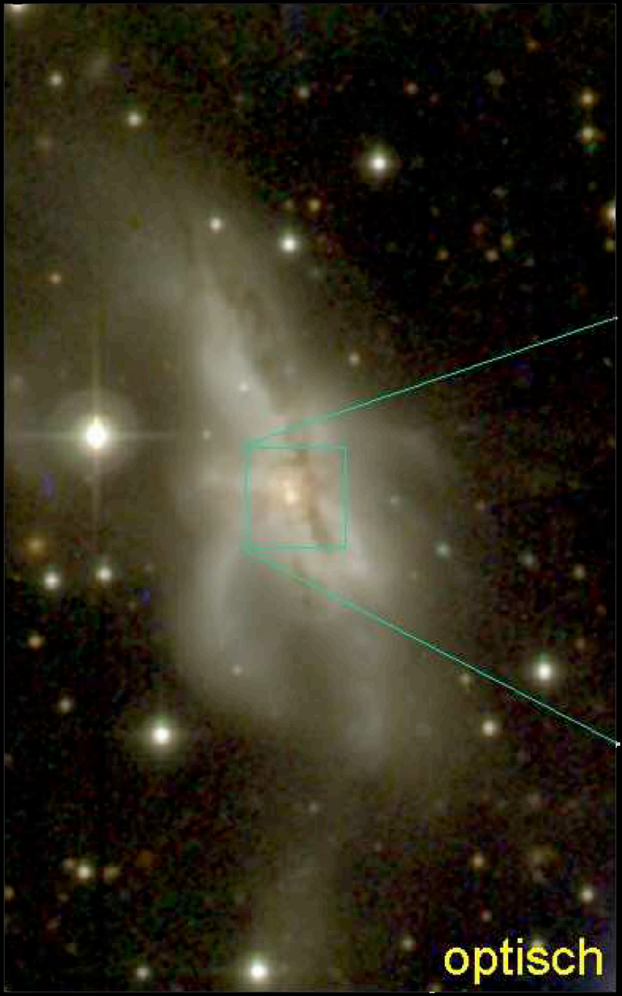
Characteristic halo sizes?

Column Densities: the other piece

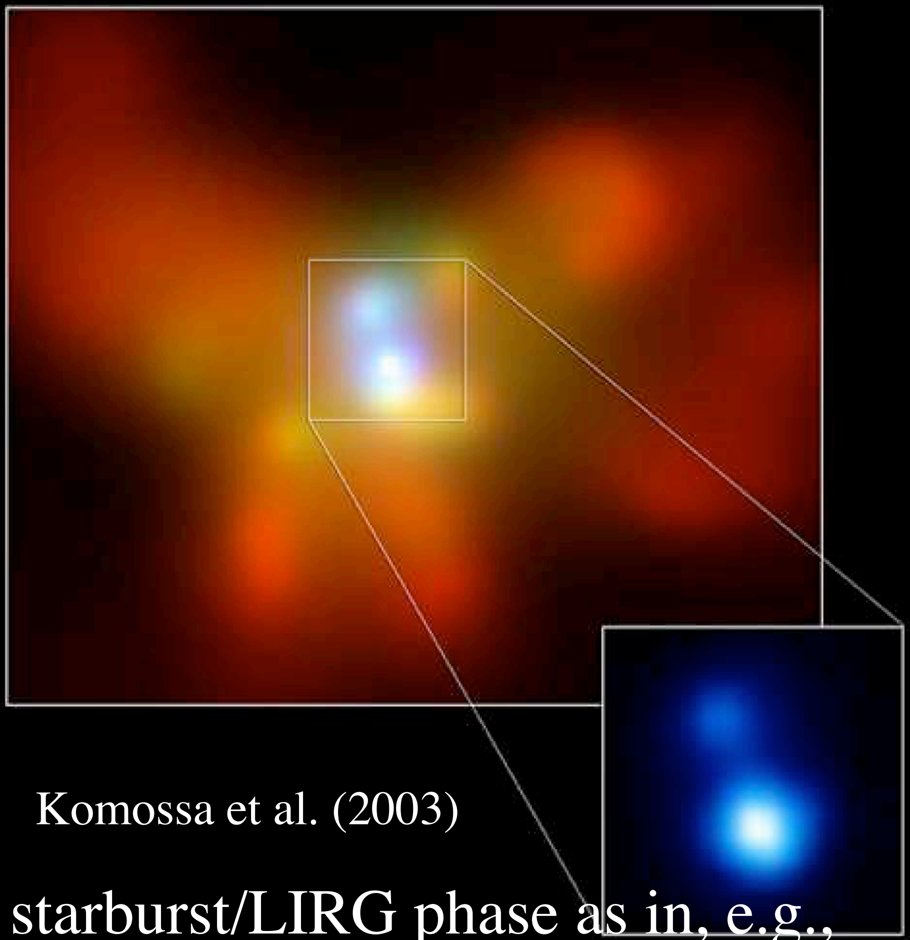


- Use multi-phase ISM calculation to get columns
- Strong evolution with quasar activity
- Gives optically *observable* quasar lifetimes ~10-20 Myr (good agreement w. obs - e.g. Martini 2004)

Buried AGN in Starbursts & ULIRGs



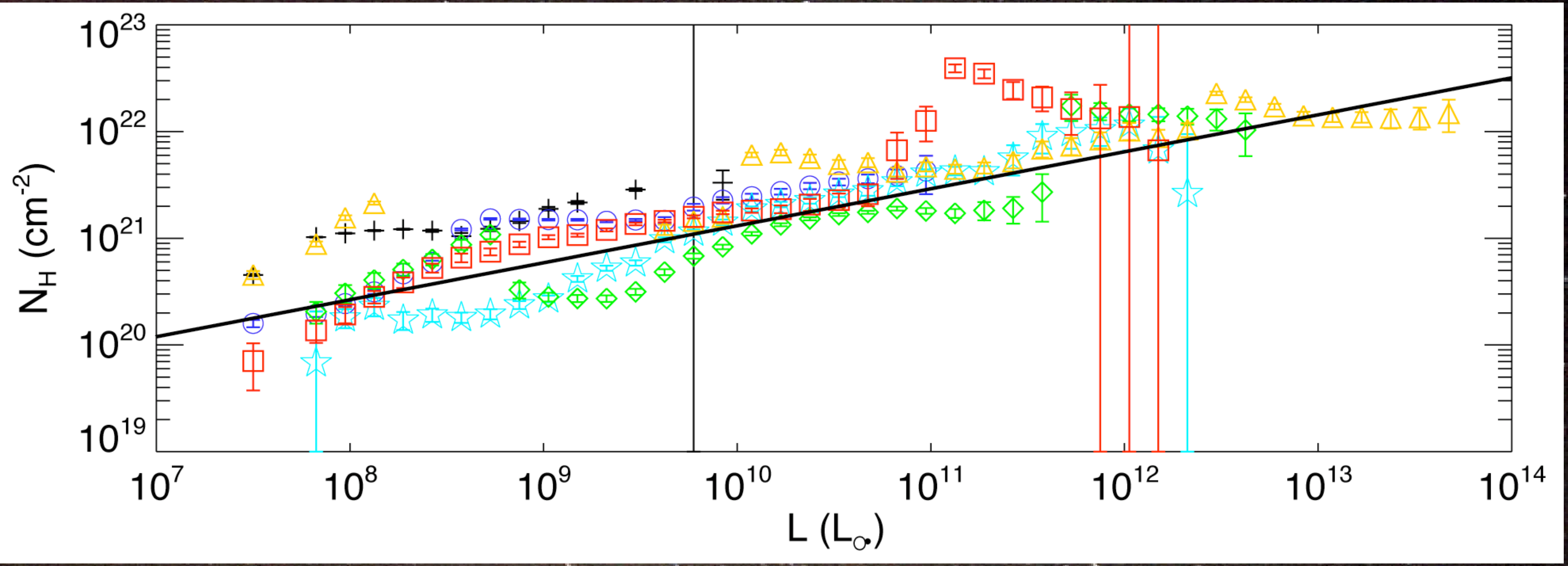
Keel (1990)



Komossa et al. (2003)

- Buried starburst/LIRG phase as in, e.g., NGC6240 (Komossaet al. 2003, Ptak et al. 2003, Alexander et al. 2005)
- Consistent with LIRG LF's (Sanders et al. 1988, 1996, Kim et al. 1995)

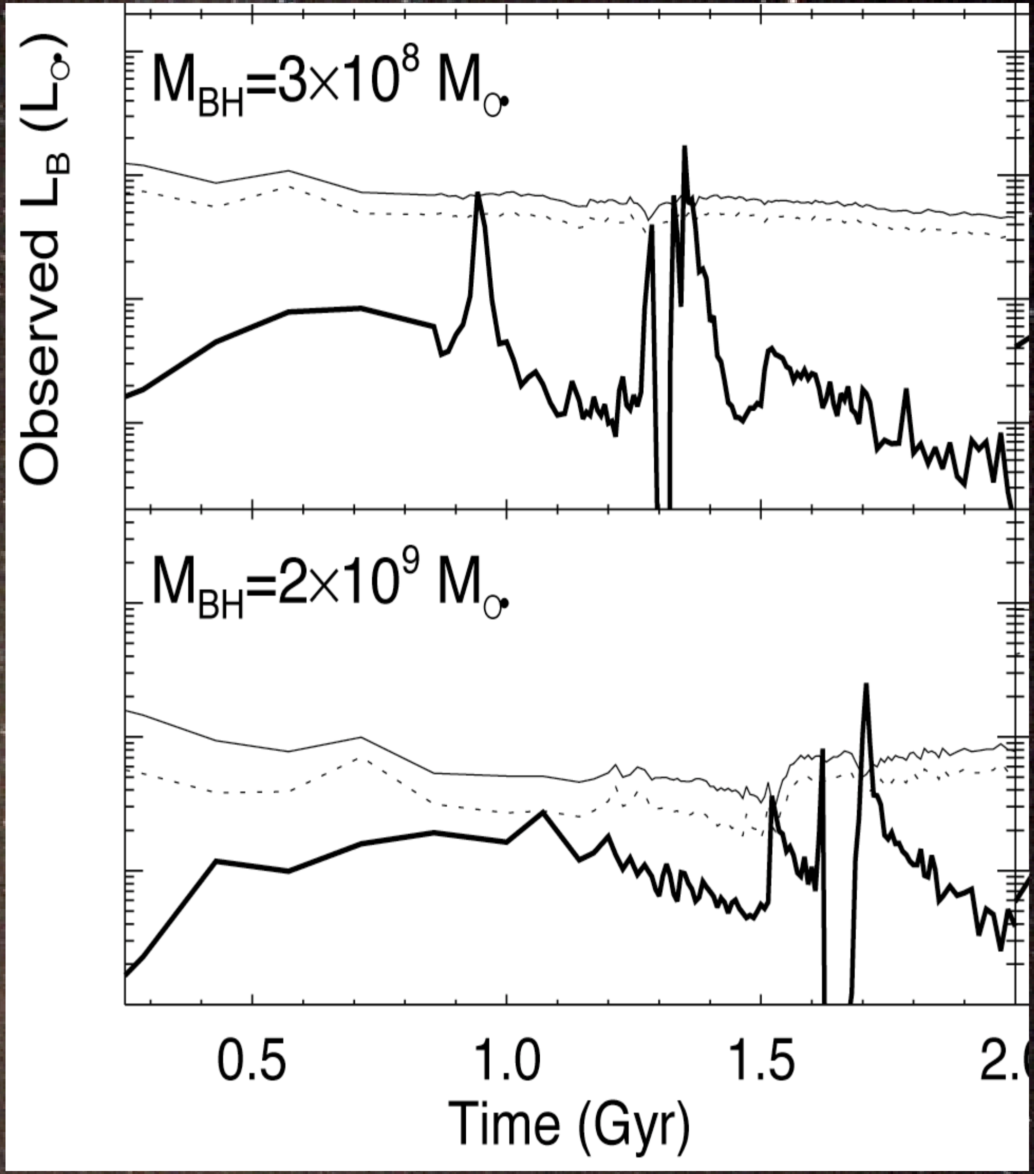
NH vs. Luminosity



- Quantify this evolution -- see correlation between typical column densities and luminosities
- Evolution dominates dispersion at any given time -- even if there's a torus, this controls how dense it is
- Similarly, no systematics w. host properties

The Broad-Line Phase

- Direct calculation - when are broad lines observable?
  - L,opt(QSO) > L,opt(gal)
- Calculate for QSO and all stars in the galaxy
- Associated with peak, within fraction ~1/4 of peak luminosity
  - Previously identified B-band observable phase

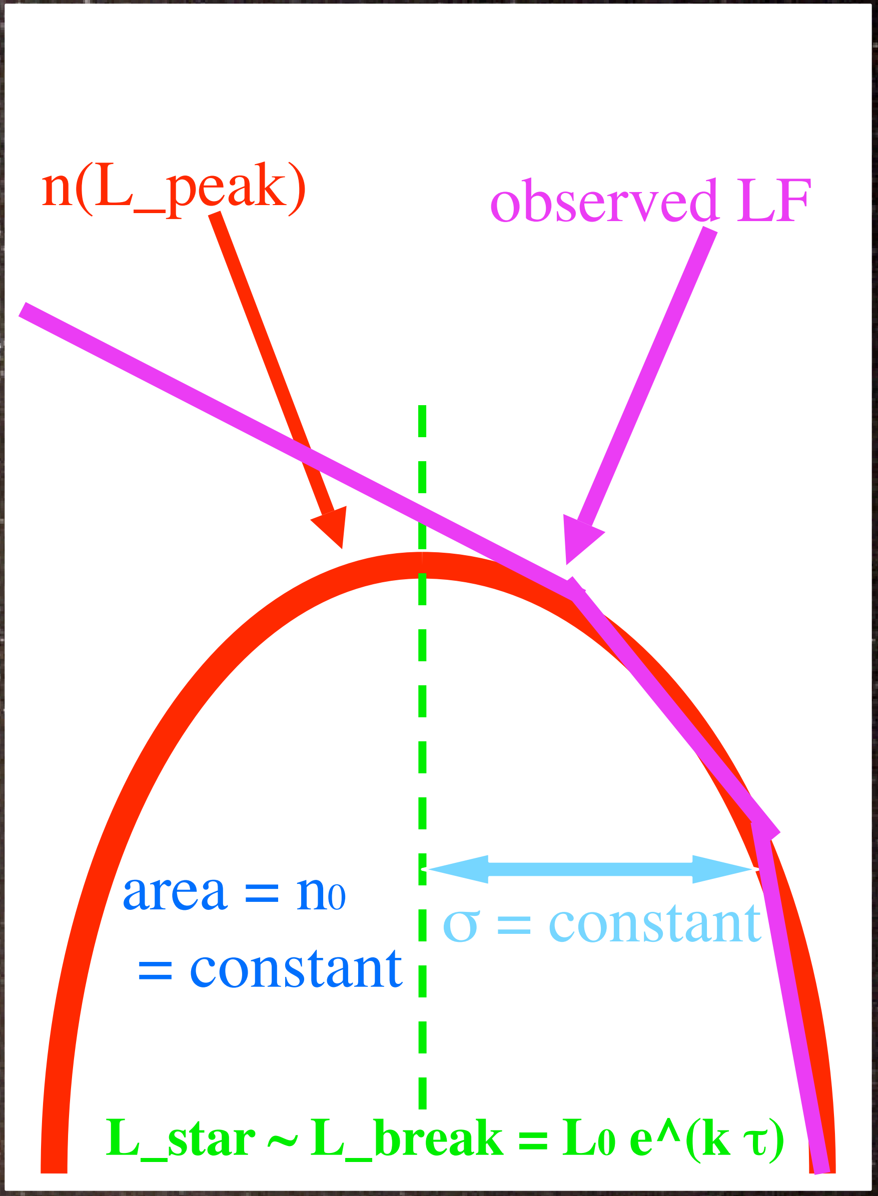


The Consequences

- We've done the overhead… how to predict?
- Semi-empirical: use the observed LF to constrain n(L_peak)
  - Once have n(L_peak), our model for quasar lifetimes + obscuration lets us predict everything else
  - Eventually, build n(L_peak) from cosmological simulations or semi-analytical models

The Luminosity Function

- Adopt a simple distribution for n(L_peak)
  - No real constraining power for faint end, other than it falling off below peak ~ break luminosity --> lognormal
  - Fit to LF
    - Still some degeneracy (width vs. location of peak)
    - Can use other observations to break (correlations)
- Compare what it predicts in all wavebands, and for all other quantities



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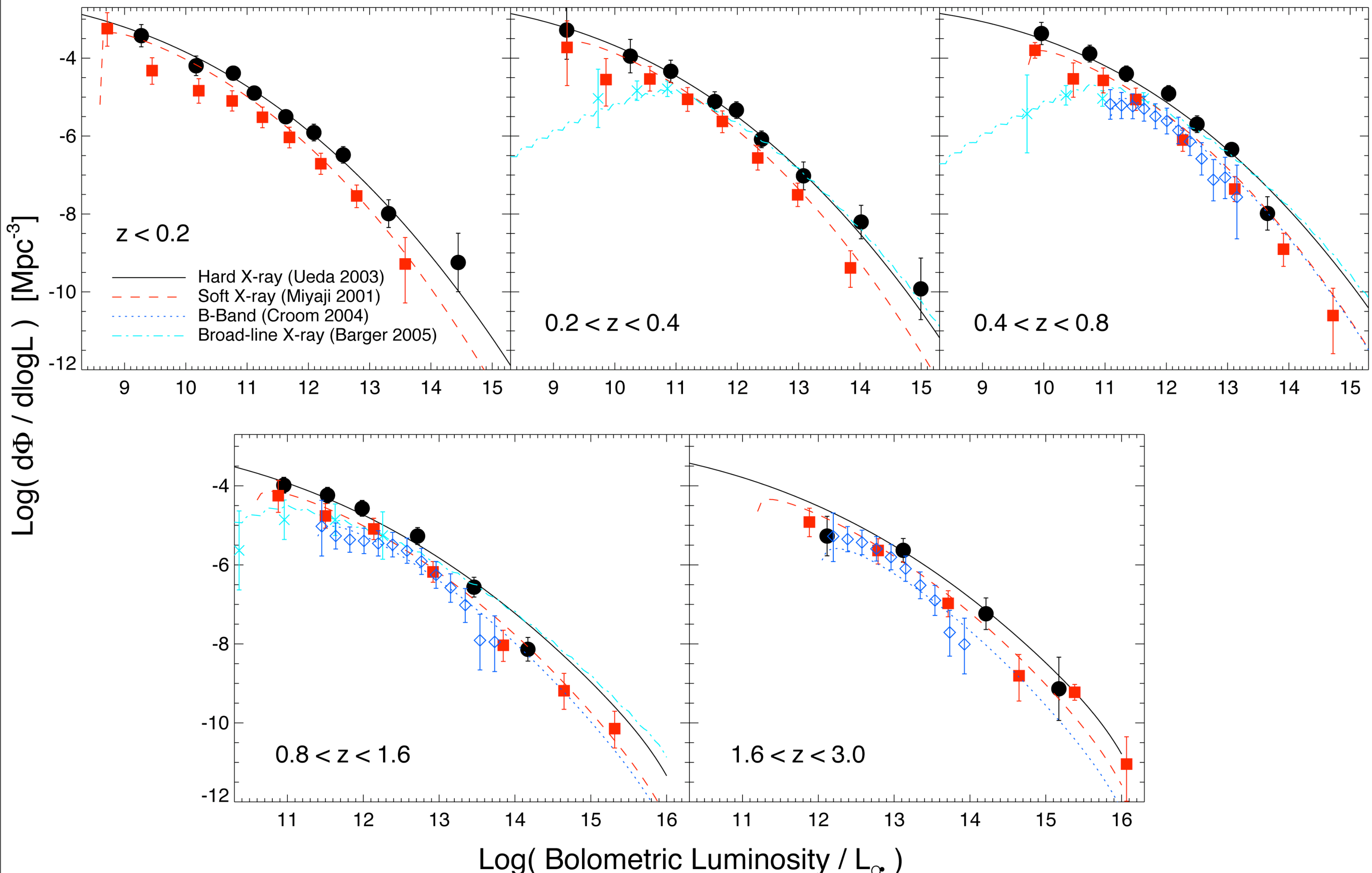
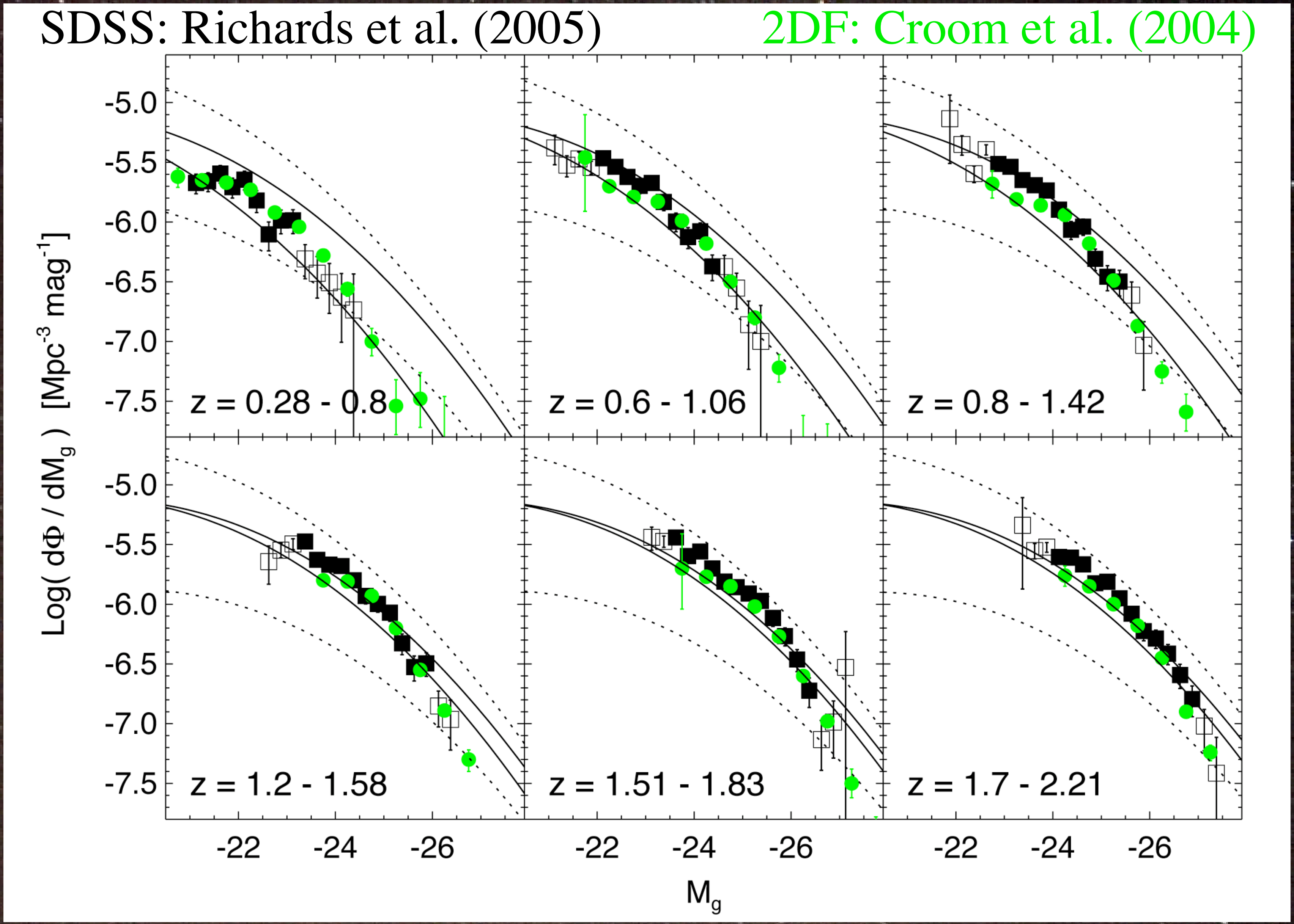
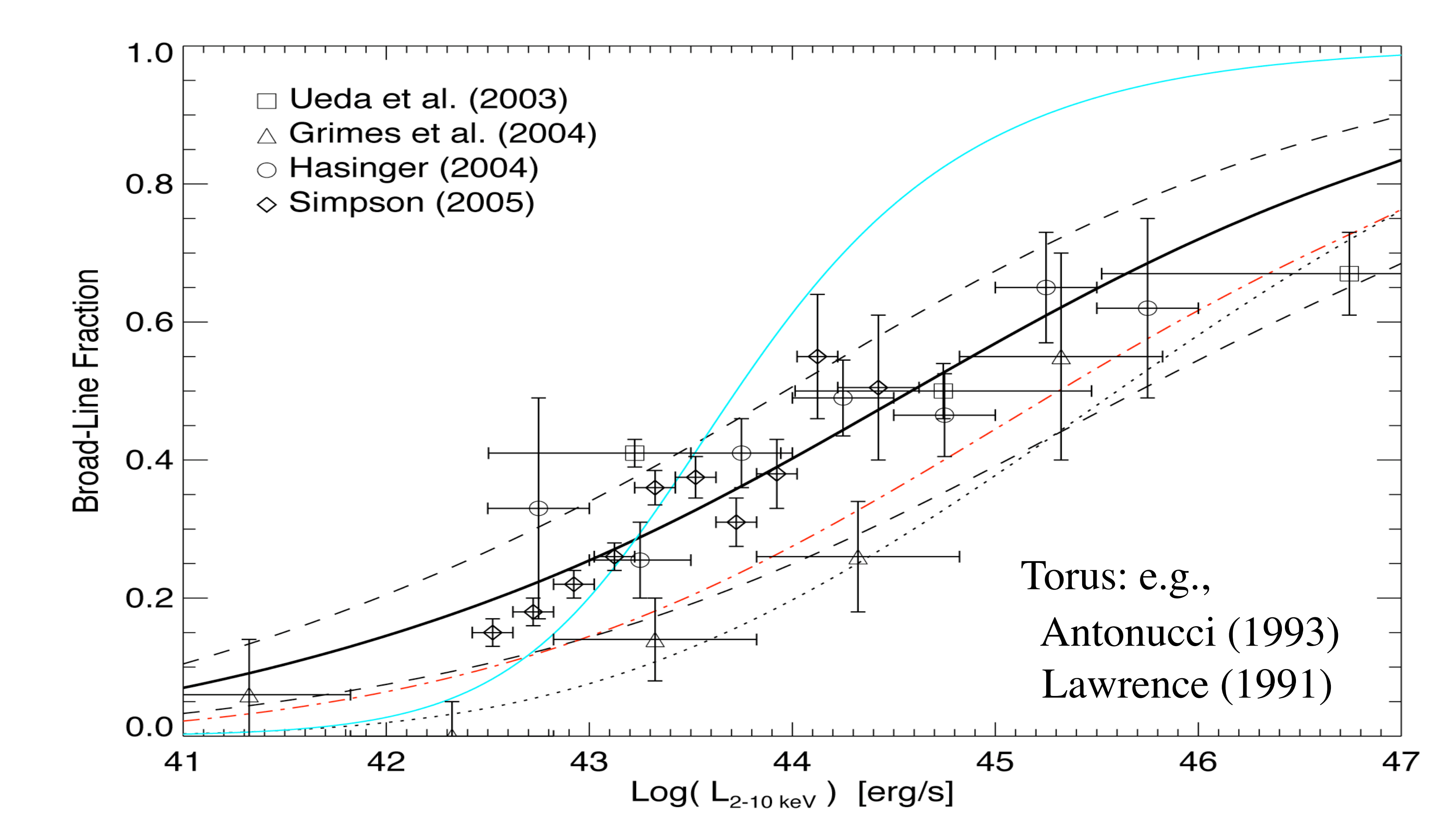


Broad-Line Luminosity Function



Broad-Line Fraction vs. Luminosity

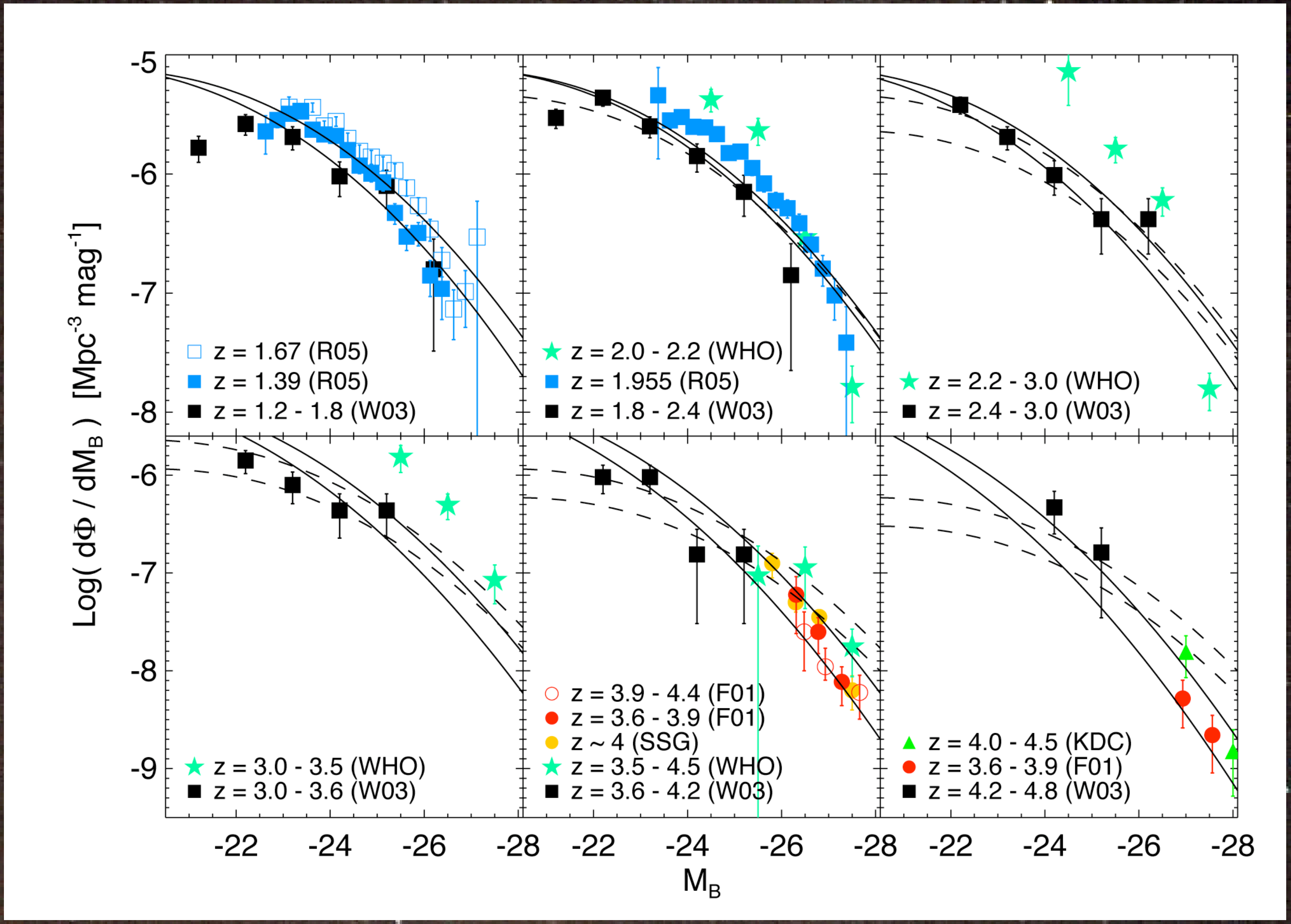


- Explains luminosity dependence of broad-line fraction without invoking luminosity-dependent torus models - better than *fitted* torus model

LFs - Extension to High-z

Constraints are weak, but the shape is easily reproduced

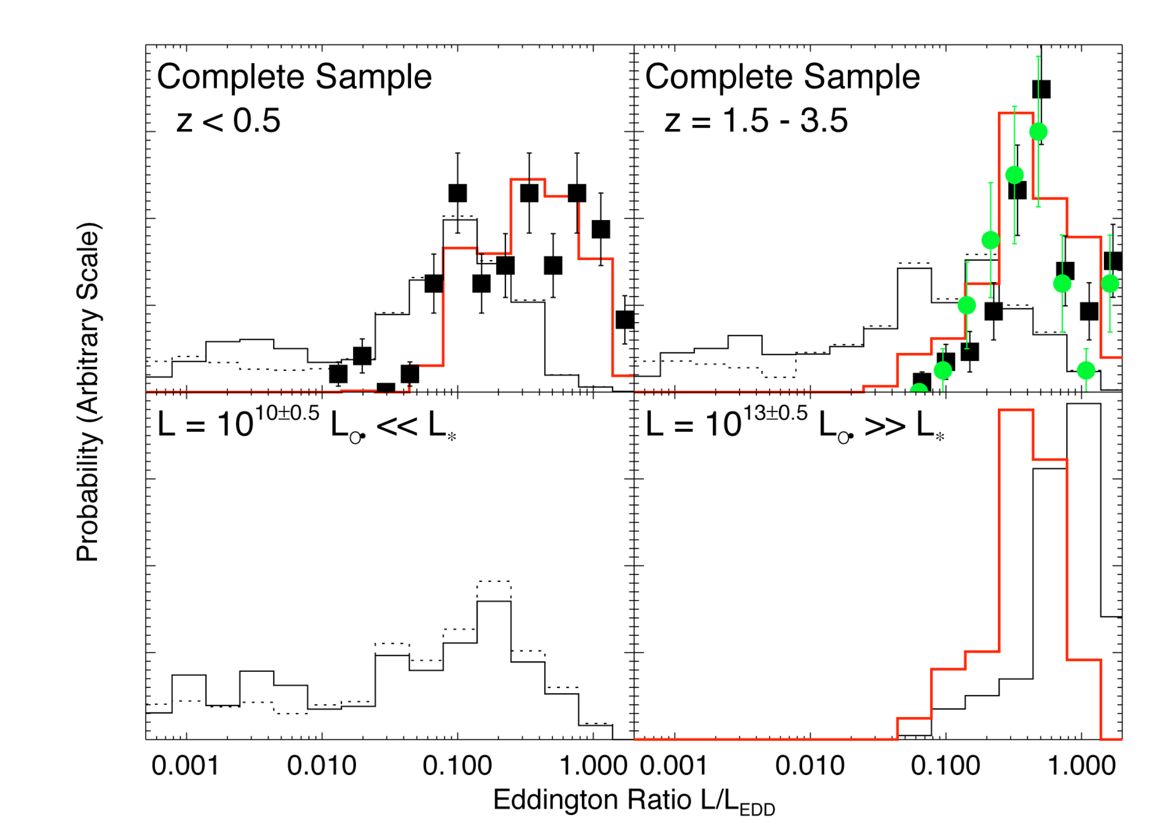
Our model allows tests PDE vs. PLE for faint-end



R05=Richards et al. (2005), W03=Wolf et al. (2003), WHO=Warren, Hewett, & Osmer (1994)
F01=Fan et al. (2001), SSG=Schmidt, Schneider, & Gunn (1995),
KDC= Kennefick, Djorgovski, & De Carvalho (1995)

Eddington Ratios

- Can predict directly from sims + n(L_peak)
- Should be different above and below break
- Immediately explains observations
  (Woo & Urry 2002, Vestergaard 2004, McLure & Dunlop 2004, Heckman 2004, Hao et al. 2005)
  - Eddington ratio dominates low-z (sub-break)
  - BH mass dominates high-z (above break)

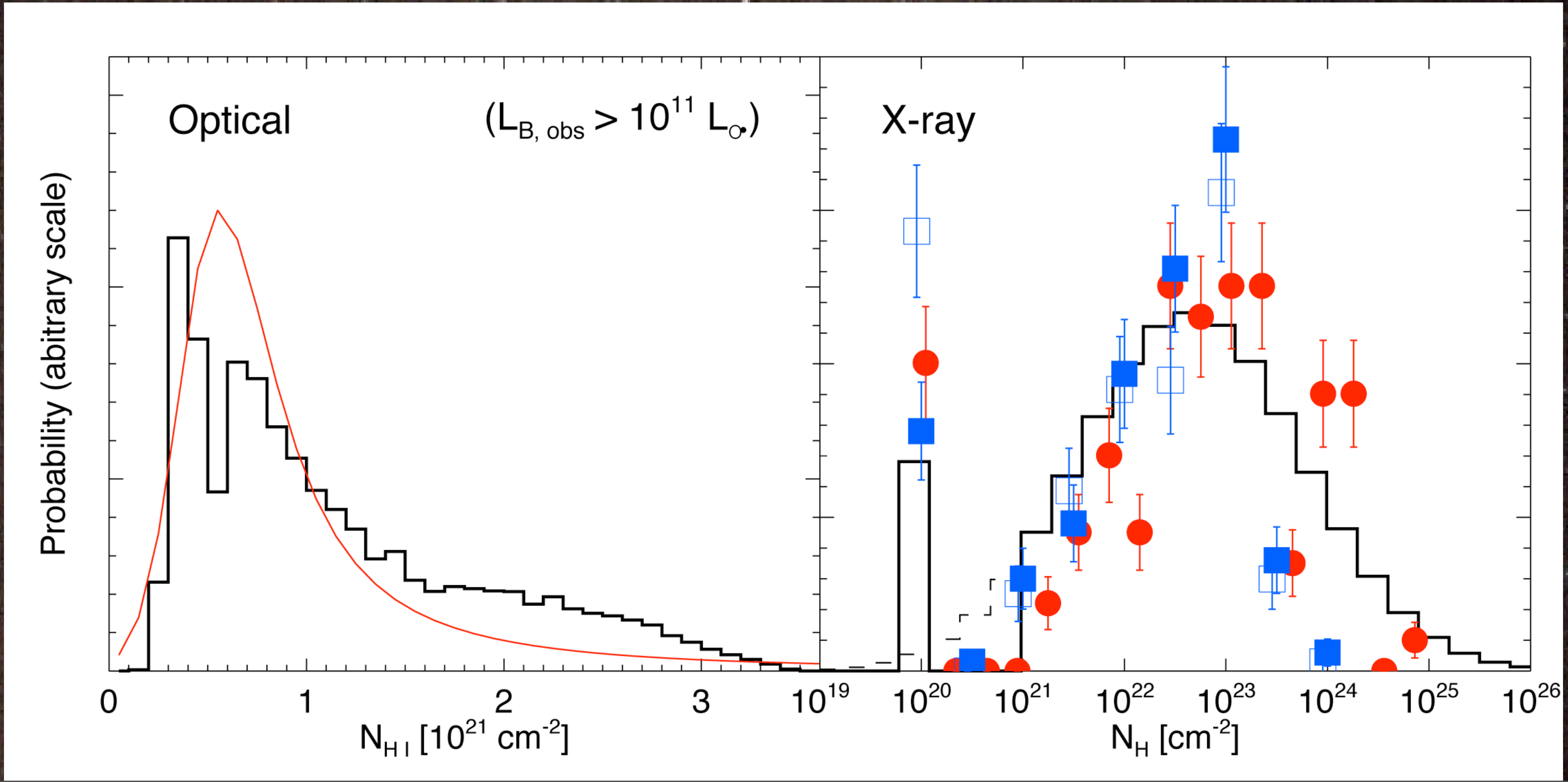


Obs: Vestergaard (2004)

The Column Density Distribution

- Integrating with the appropriate selection function, we reproduce both X-ray and optical NH distributions
- Naturally produce Compton-thick pop.

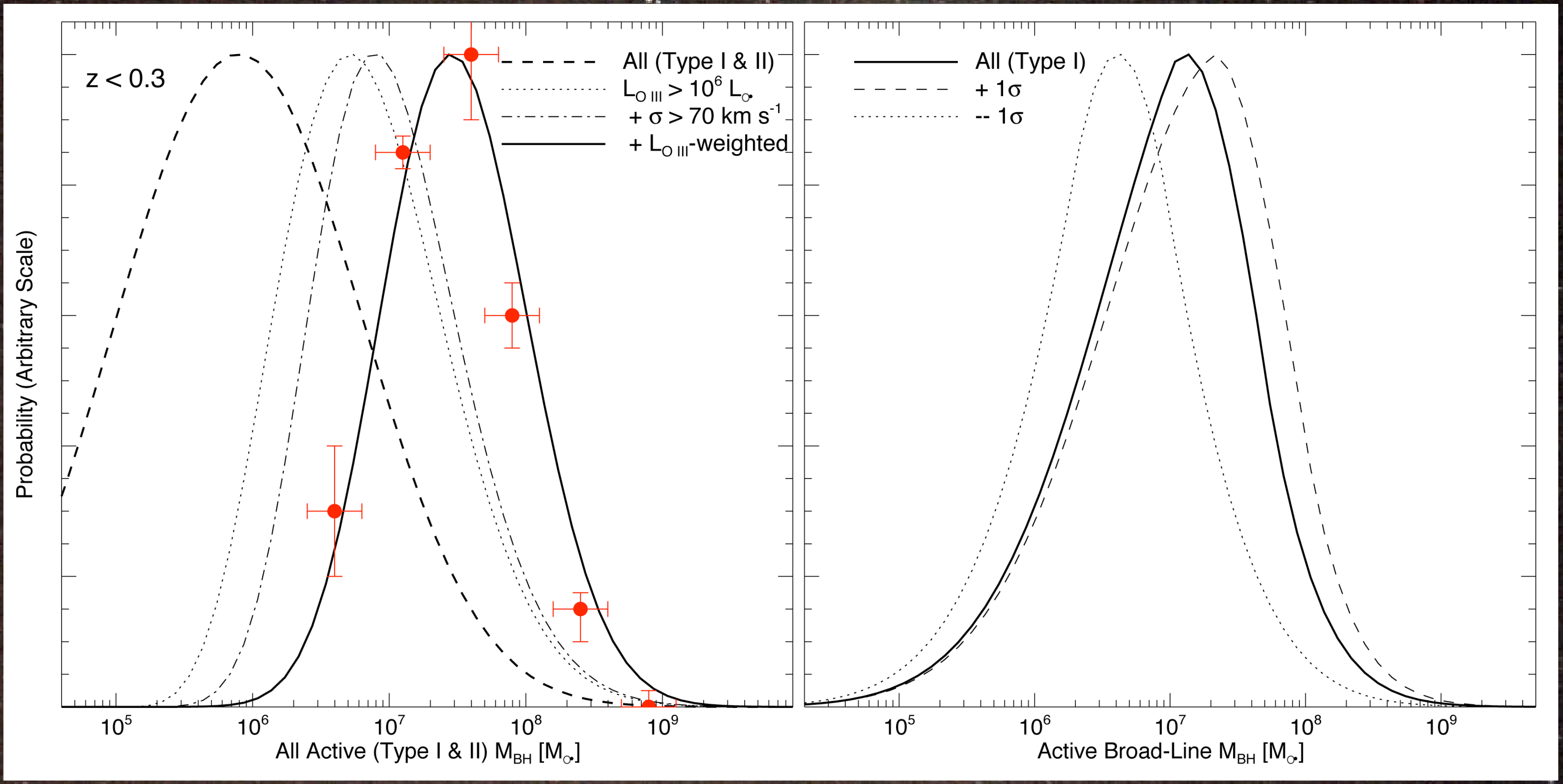
Obs: Hopkins et al. (2004)



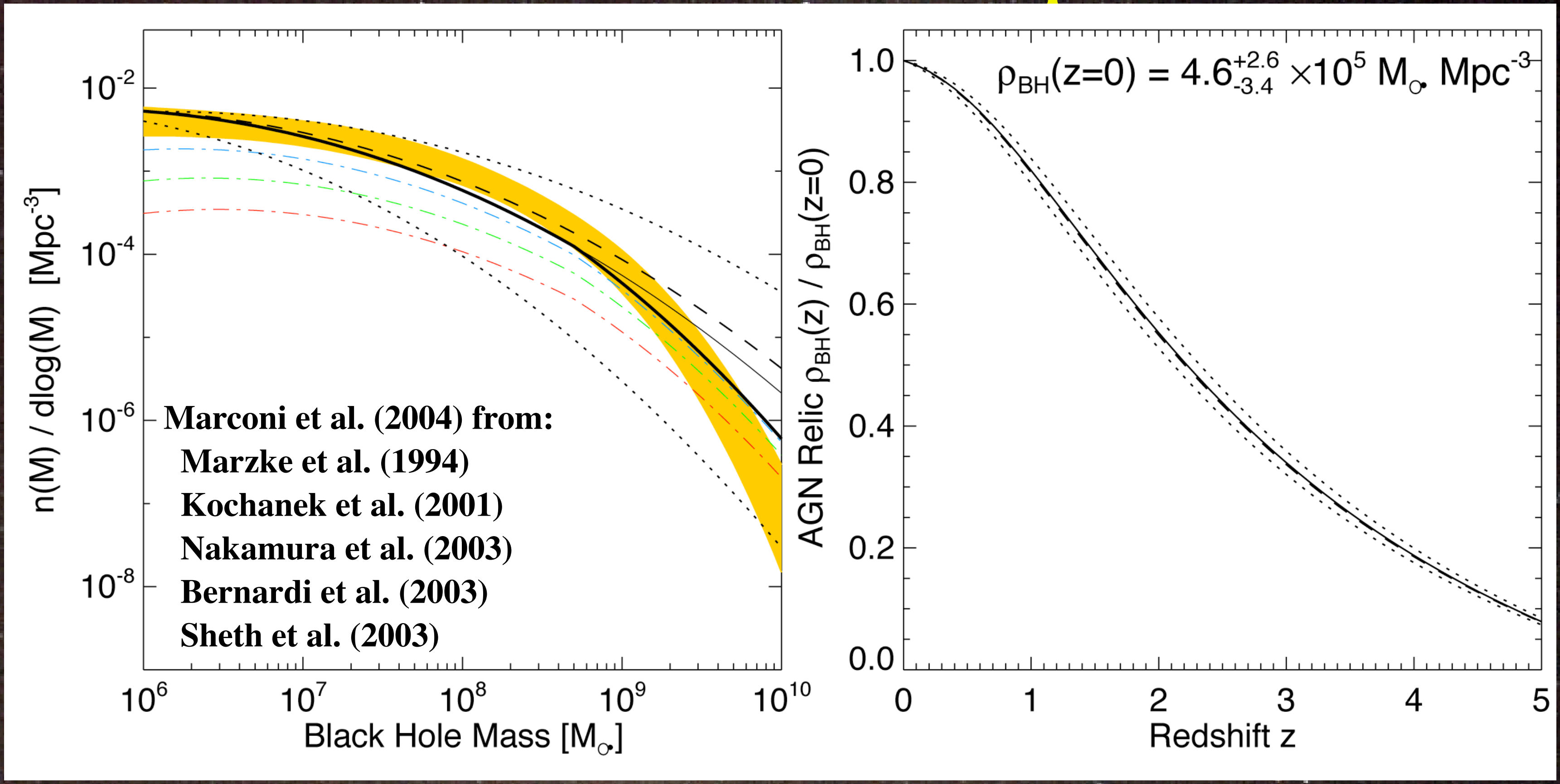
Obs: Triester et al. (2004)
Mainieri et al. (2005)

The Active SMBH Distribution

- L_peak -> black hole mass
- Can determine for all objects (e.g. Heckman 2004) and for broad-line only (Greene et al., in prep.)



The Relic SMBH Population



- From n(L_peak), immediately know rate of production of SMBHs of a given mass - integrate
- Mass function and total density
- Anti-hierarchical BH growth

Host Galaxy Properties

Our Merger modeling -> [Spheroids and SMBH produced *together*]

- M-sigma relation (Di Matteo et al. 2005)
- Fundamental Plane (Robertson et al. 2005)

Pahre et al. (1998)
Gebhardt et al. (2000),
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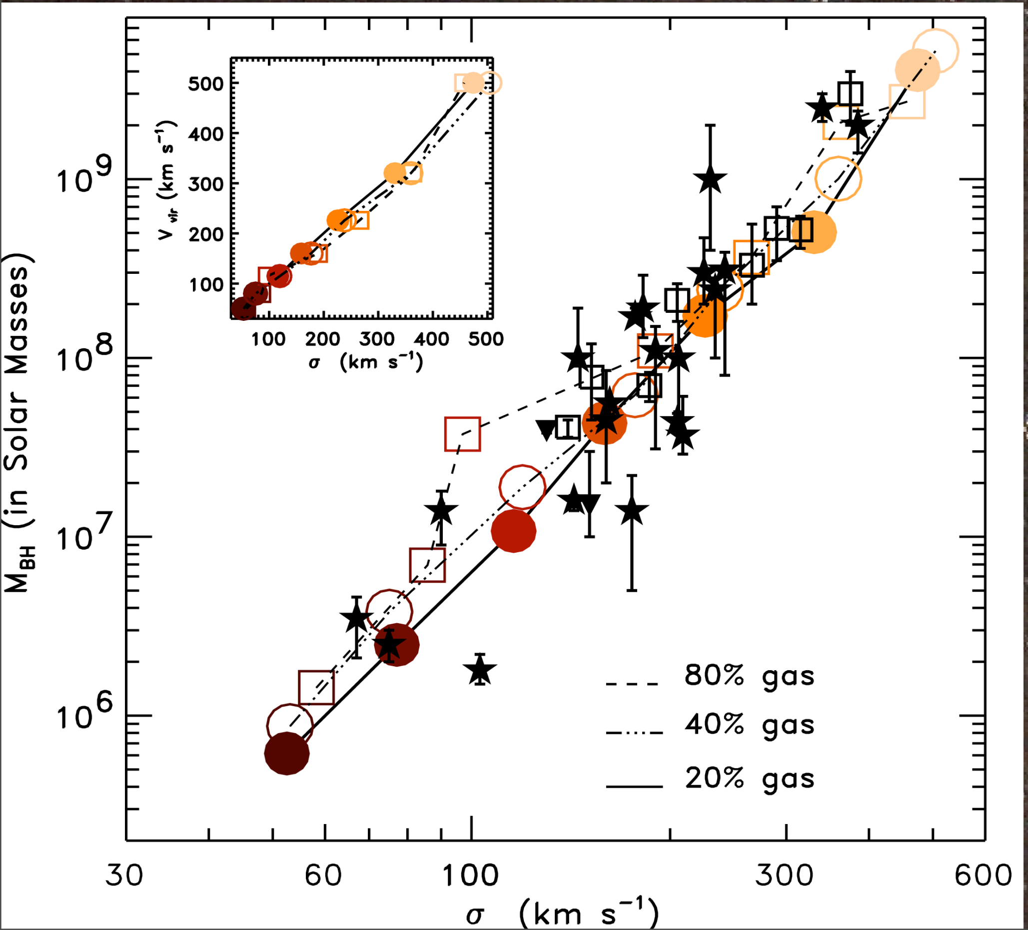

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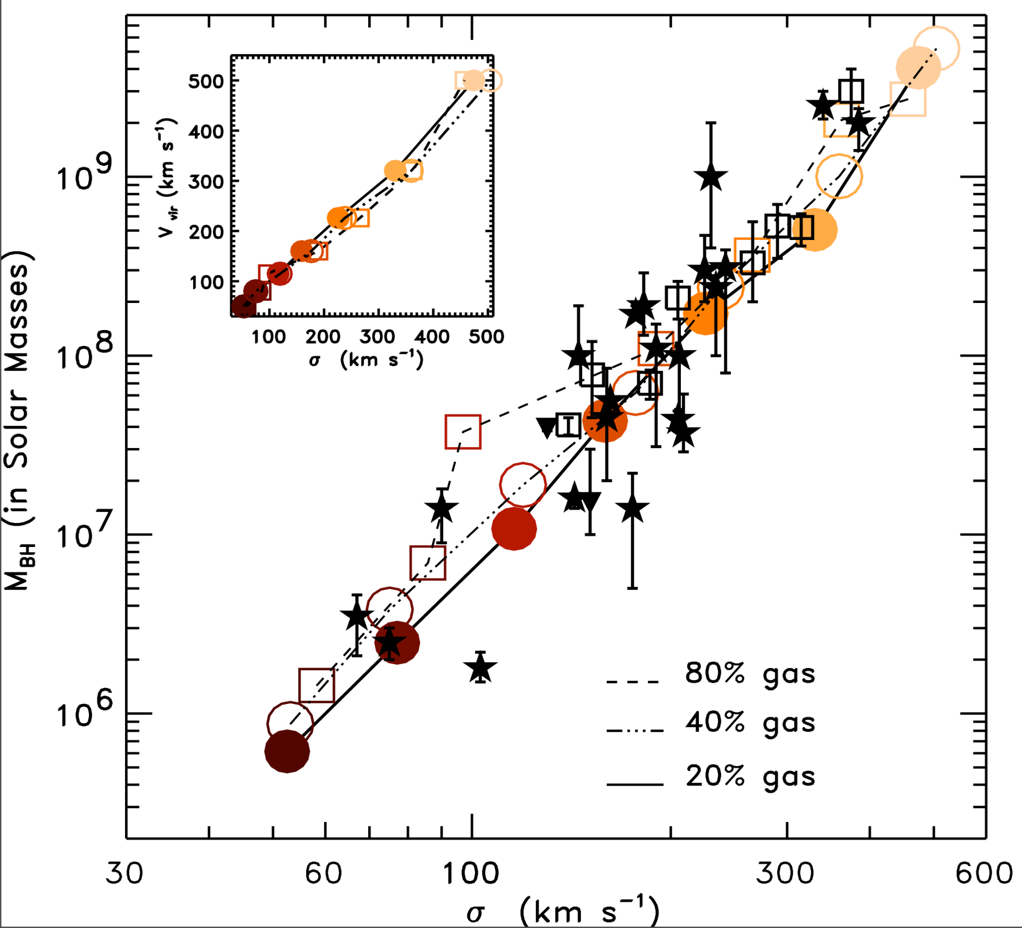
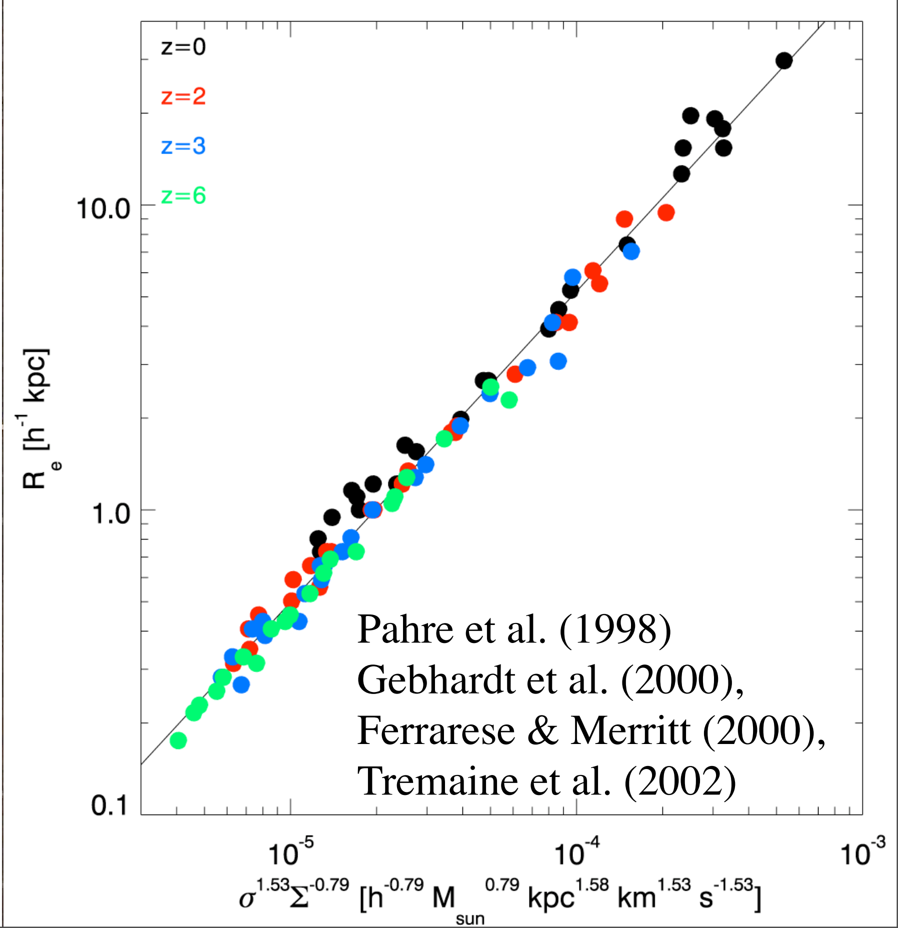
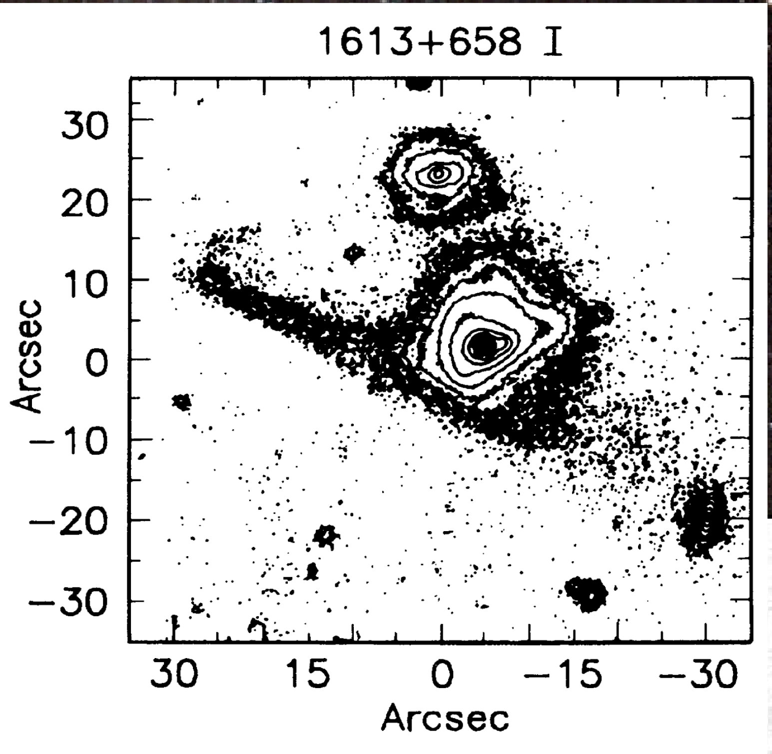
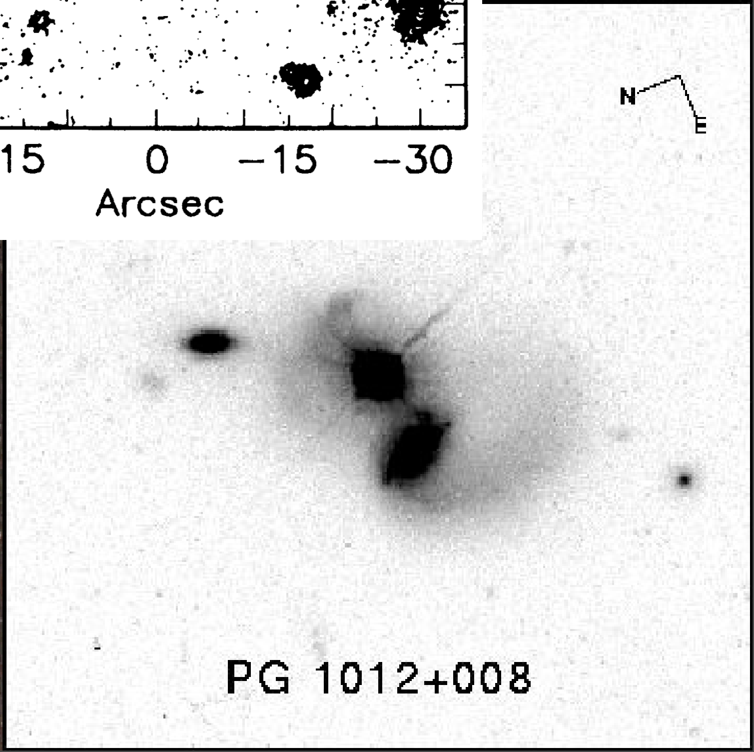




Constraints on BH Growth?

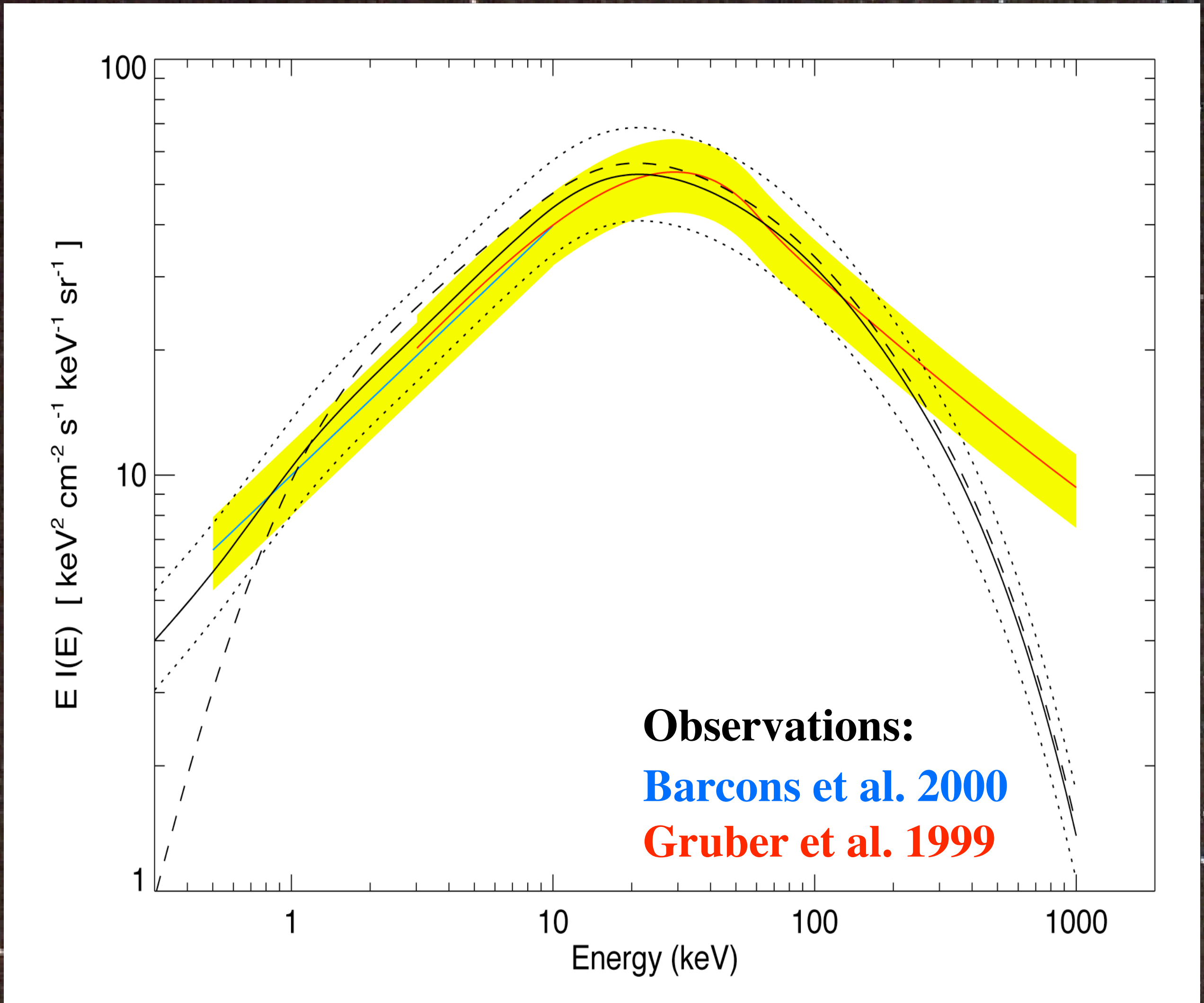
- Numerous possibilities to re-excite activity: Seiferts, LINERs, etc.
- But, SMBH density + mass function constrain
  - Mass from mergers
- Can you keep M-sigma with slow "trickle" accretion?





Hutchings & Neff (1992)
Bahcall et al. (1997)

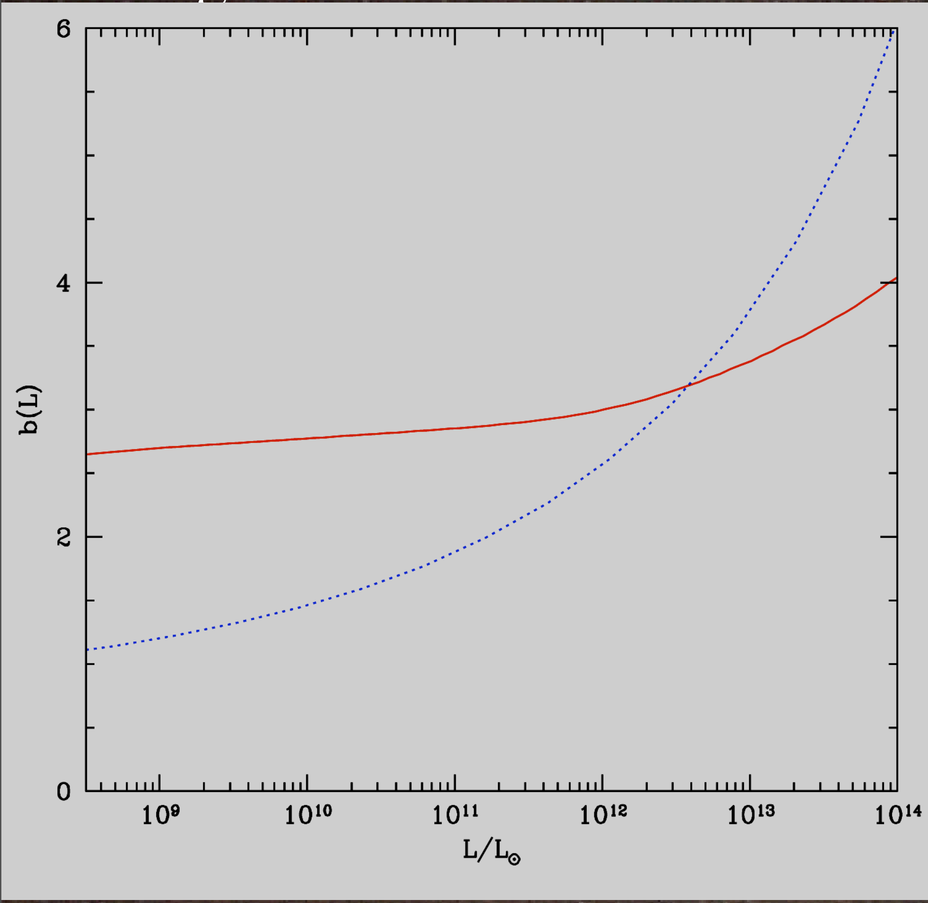
The X-Ray Background

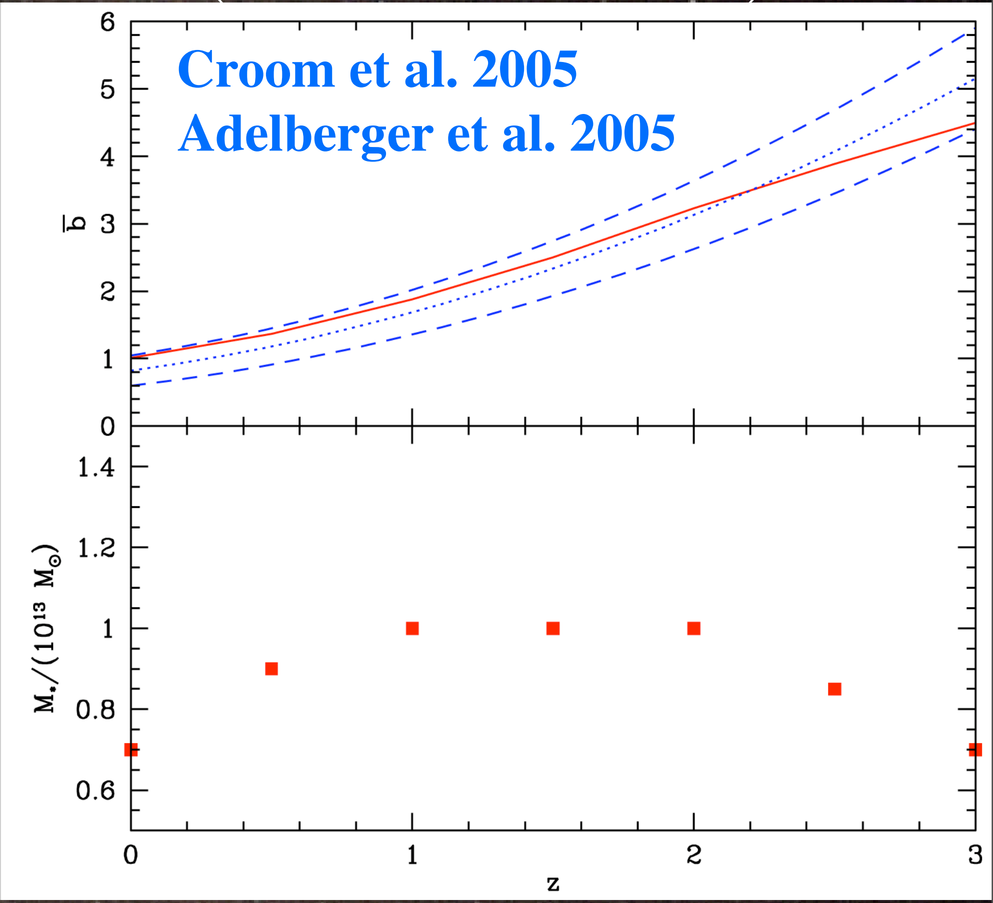


- Integrate spectrum of each L_peak
- No need to invoke arbitrary obscured pop.
- Luminosity and peak luminosity dependencies key

The Quasar Correlation Function

- Peaked n(L_peak) -> characteristic final black hole mass -> characteristic host halo mass
- Below the LF break, clustering is *flat* with luminosity
- Merger driven -> excess on small scales (Hennawi et al. 2005)





Summary

Quasar Lifetimes/Light Curves:

VS.

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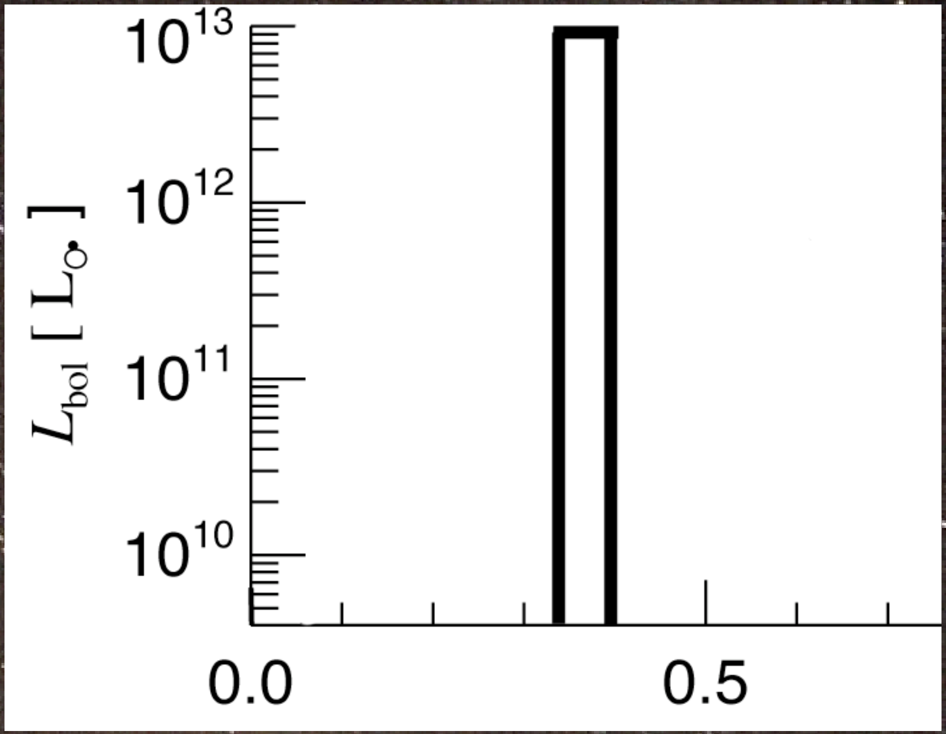

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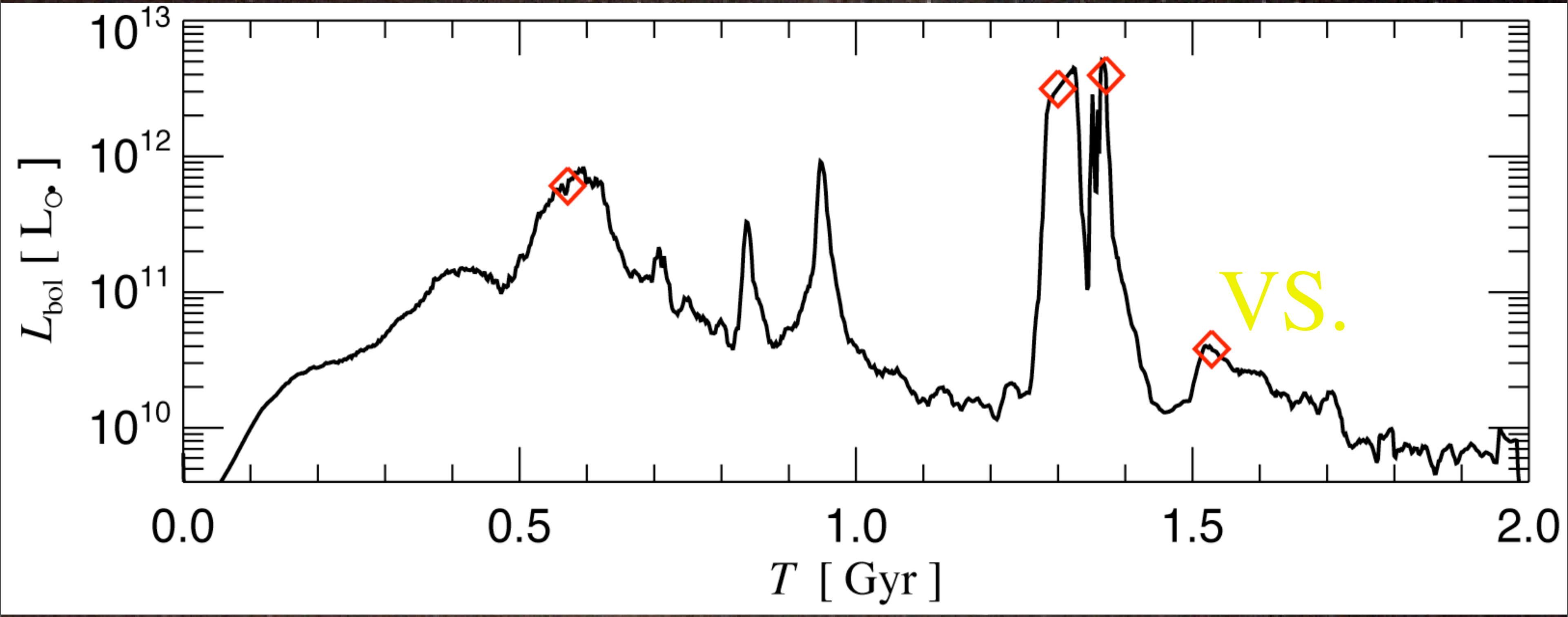

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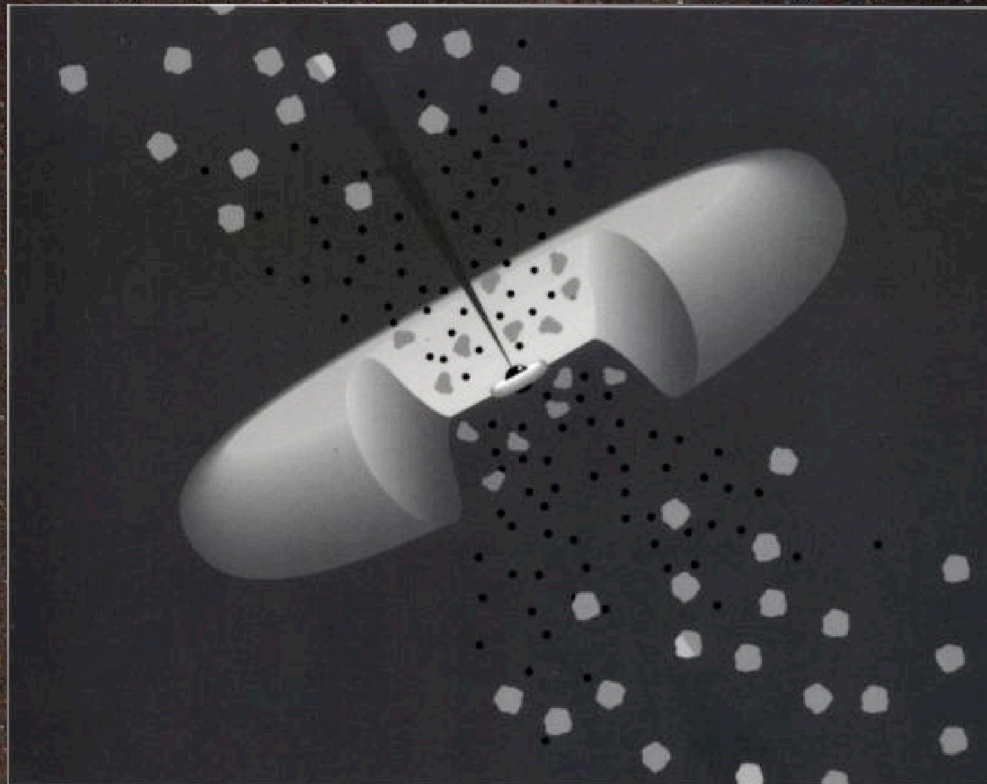

VS.

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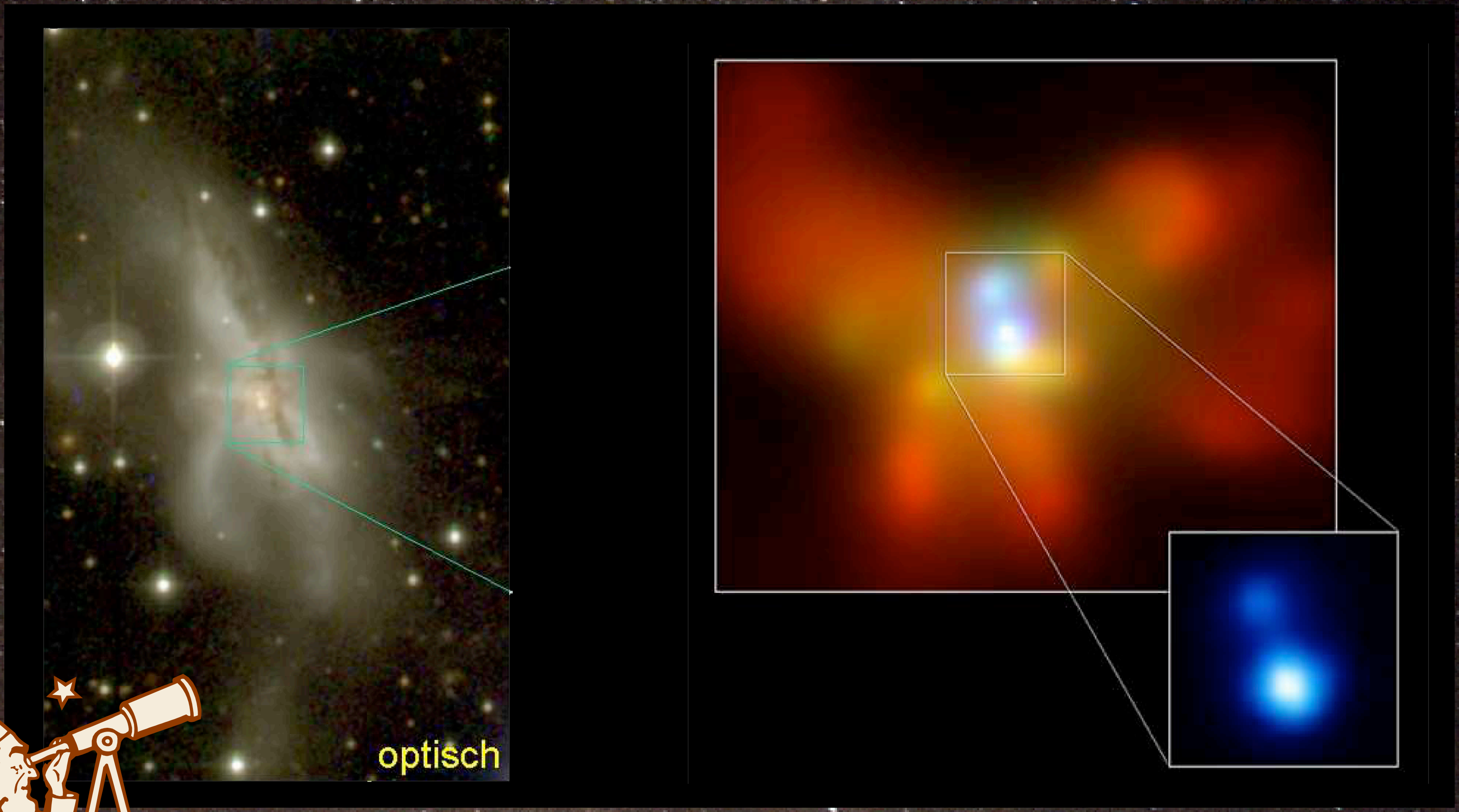

Quasar lifetimes are luminosity dependent -> new interpretation of the LF

Quasar obscuration is evolutionary, not static

- Proper accounting of these two facts predicts a host of observations:
  - **Luminosity function at all other frequencies, faint end LF slope**
  - **Broad-line fraction as a function of luminosity**
    - **Broad-line luminosity function in optical and X-ray surveys**
  - **Column density distributions: optical and X-ray**
  - **Quasar lifetimes**
  - **Eddington ratio distributions and evolution with redshift**
  - **Evolution of characteristic BH masses with redshift**
  - **Active BH mass distribution: Type I & Type II**
  - **SMBH mass function and density at z=0**
    - **Galaxy velocity dispersion and bulge luminosity distributions**
  - **Quasar bias and correlation functions**
  - **Turnover in elliptical BH mass distribution (e.g. Sheth et al. 2003)**
  - **Sub-mm - QSO obscuration correlations (e.g. Page et al. 2004)**
  - **High-redshift radio source counts (Haiman et al. 2004)**
  - **Starburst/ULIRG populations … and more to come**

Where to From Here?

- Observations:
  - Better faint-end constraints on n(L_peak), not the LF
    - BH mass functions
    - Radio counts
    - Correlation functions vs. L
  - High-z LFs
  - *Combine* all these observations to constrain n (L_peak)
  - Numerous tests:
    - Eddington ratio distributions
    - NH distribution vs. L
    - QSO correlation
    - Active BH mass functions

- Theory:
  - How do we get n(L_peak) ?
    - Cosmological simulations
    - Semi-analytical models
  - Why is there a characteristic L_peak(z) ?
    - Typical QSO host mass?
  - Use QSOs & n(L_peak) -> predict galaxy properties
    - LF's, colors, masses, sigma
  - IR properties; ULIRGs
  - Numerous calculations to revisit with better models for quasar lifetimes

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