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

Hopkins, et al 2006

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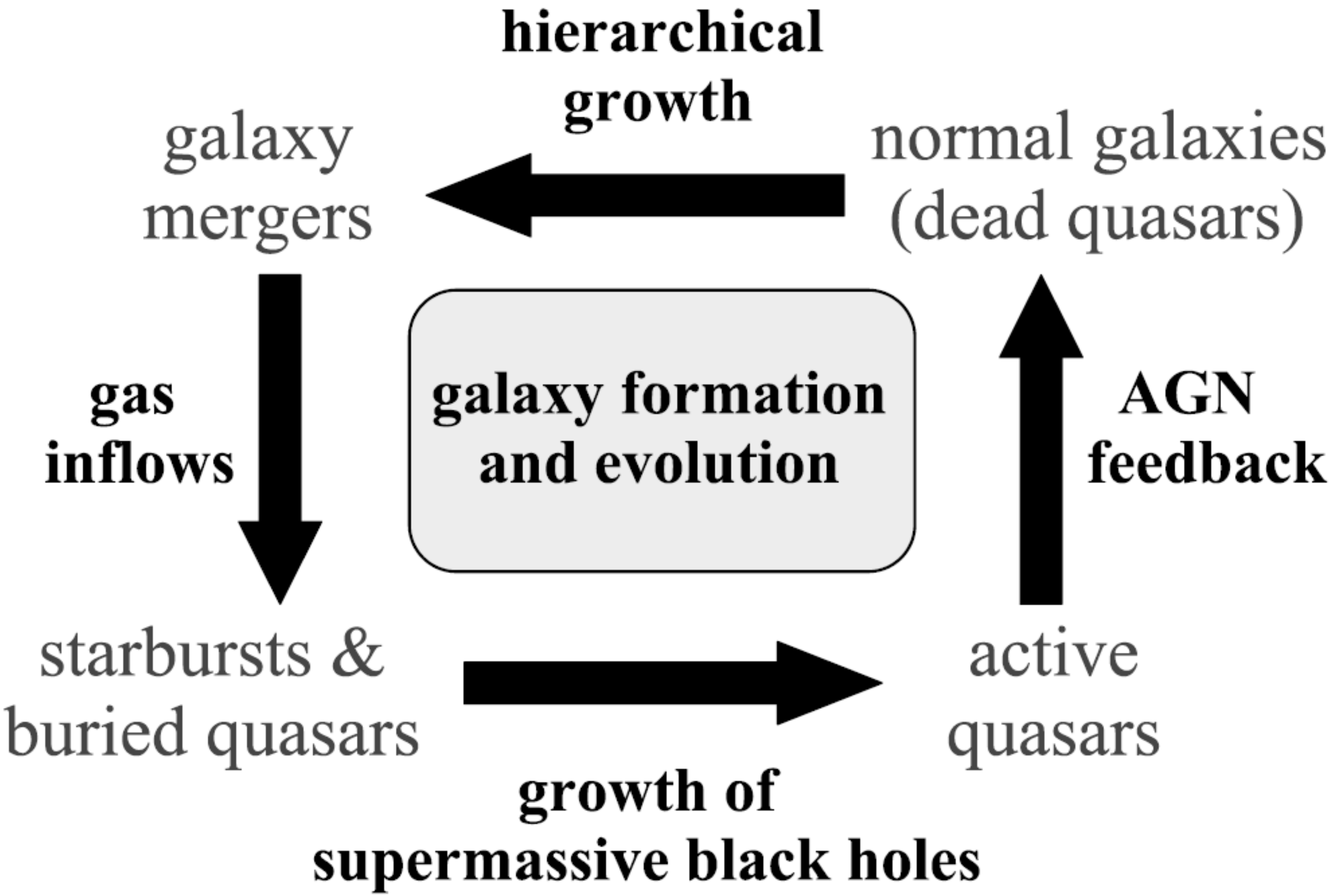
Motivation

- Standard initial conditions can be used to make highly accurate simulations of Lyman-α forest
  - Existing *ab initio* models from these same conditions have failed to yield a galactic population representative of observations
- Therefore, believe ΛCDM and the initial conditions but not the galactic evolution models
- Need a new a model with the “missing physics”
  - Additional hydrodynamical processes including star formation and feedback from black hole accretion and supernovae



hierarchical growth

galaxy mergers

normal galaxies (dead quasars)

gas inflows

galaxy formation and evolution

AGN feedback

starbursts & buried quasars

active quasars

growth of supermassive black holes

Methodology

- Simulate hundreds of mergers
- Find luminosity for merged galaxies as a function of time
- Bin mergers by L_{peak}
- Quasar luminosity function φ(L) is the convolution of quasar lifetime $t_Q(L|L_{peak})$ with the rate of quasar births $\dot{n}(L_{peak})$
  - ☐ Use calculated t_Q and measured φ to find $\dot{n}(L_{peak})$

- And you get $n\left(L, L_{\nu}, M_{BH}, N_H, L_{peak}, M_{BH}^{f} \mid z\right)$

Simulation

- Smoothed particle hydrodynamics
- Radiative heating and cooling
- Star formation and supernova feedback
  - “subresolution model of a multiphase interstellar medium” (Springel & Hernquist MNRAS 2003)
- Black hole is “sink” particle
    - Accretion determined by Eddington-limited version of Bondi-Hoyle-Lyttleton accretion theory (Bondi 1952)
  - Radiates at $L_{bol}=\varepsilon_r M_{BH} c^2$
    - $\varepsilon_r=0.1$ (parameter?)
    - Assume ~5% of radiation couples dynamically to surrounding gas

Calculating Quasar Lifetimes

$$t_Q\left(L \mid L_{peak}\right) = t_Q^* \int_L^{L_{peak}} e^{-L/L_Q^*} d \log L$$

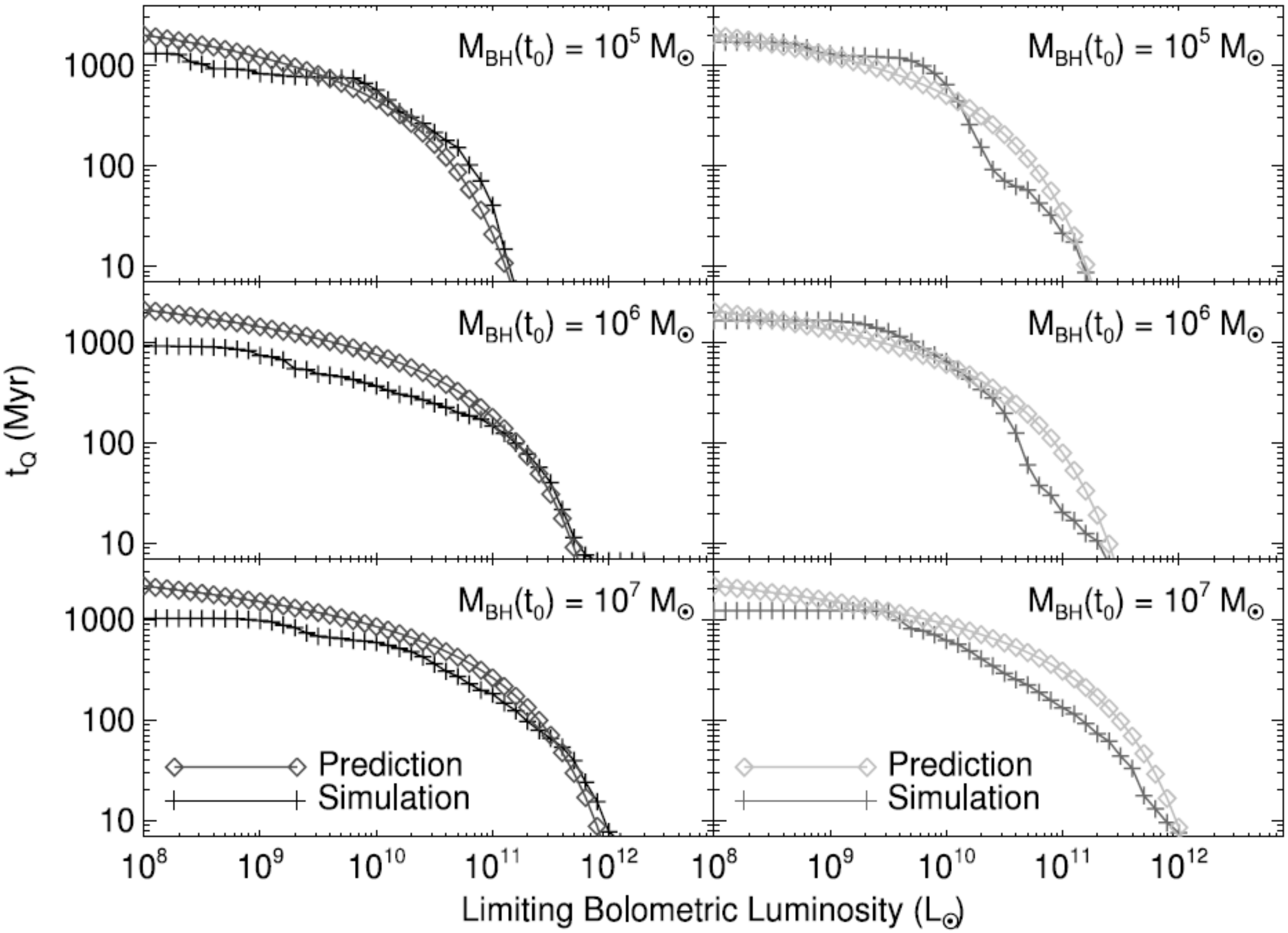
- $t_Q(L|L_{peak})$ = the time a quasar has a luminosity above L

  with $t_Q^* = t_*^{(10)} \left(\frac{L_{peak}}{10^{10} L_\Theta} \right)^{\alpha_T}$, $L_Q^* = \alpha_L L_{peak}$

  and parameters fitted from model:

  $t_*^{(10)} = 1.37 \times 10^9 yr, \alpha_T = -0.11, \alpha_L = 0.20$

- This formula predicts ~90% of quasar lifetime near $L=0.001 L_{peak}$!



Without/with
bulge

Getting Quasar Creation Rate $\dot{n}$

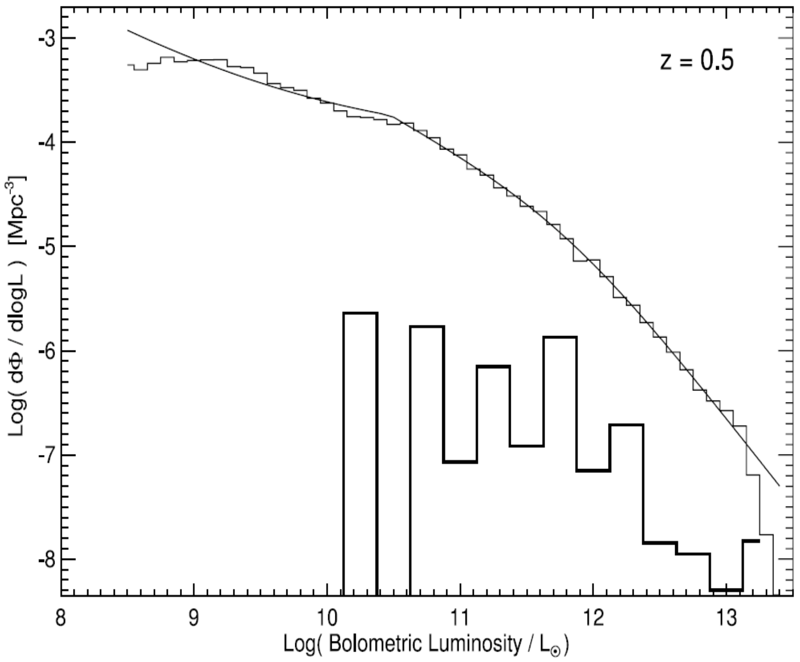
- φ = the comoving number density of quasars in Δlog *L*

$$\phi(L) \equiv \int \frac{dt_Q\left(L \mid L_{peak}\right)}{d\log L}\,\dot{n}\left(L_{peak}\right) d\log L_{peak}$$

- Approximate the above with a sum and fit:

$$\phi(L) \approx \sum_i \dot{n}\left(L_{peak,i}\right)\left\langle \frac{\Delta t_Q\left(L \mid L_{peak,i}\right)}{\Delta \log L} \right\rangle$$

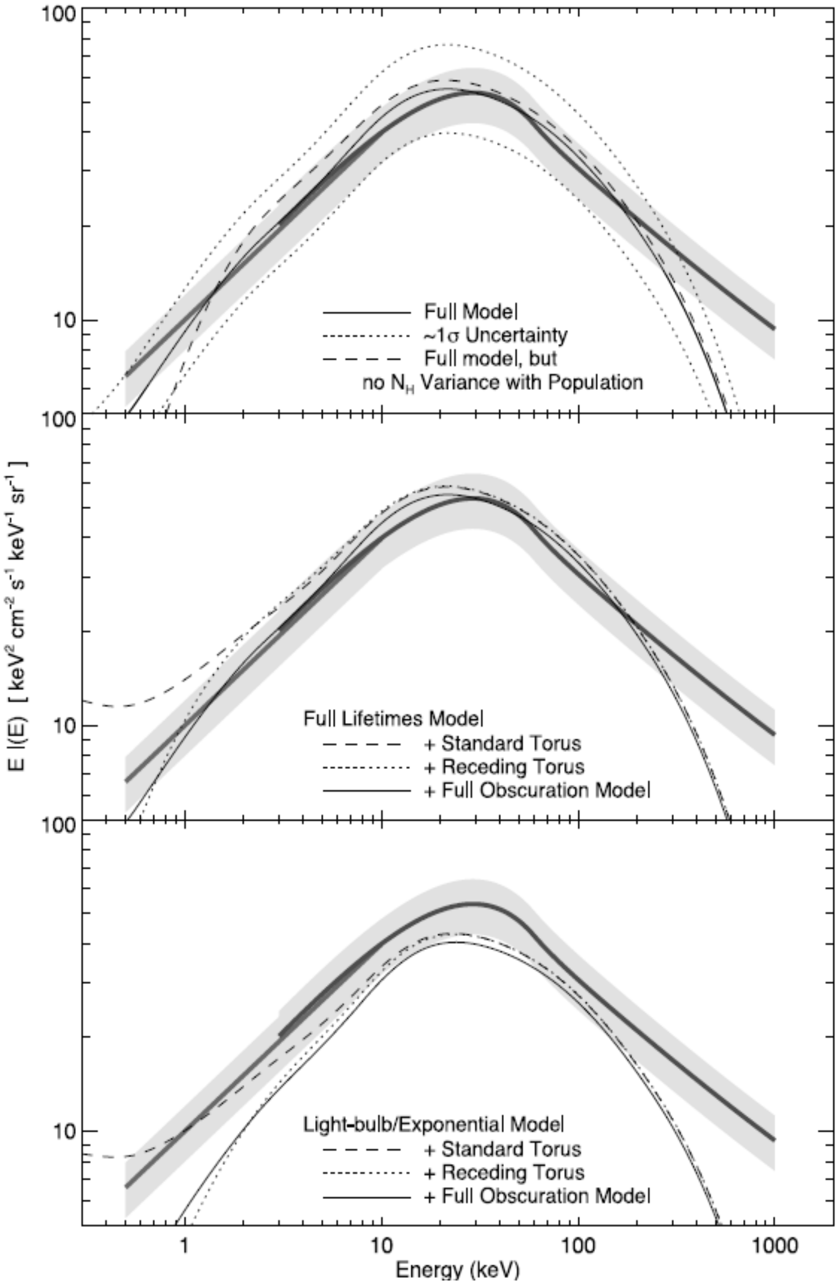
- $\dot{n}$ can be extrapolated to arbitrary z



Curve shows hard x-ray quasar luminosity function from Ueda et al (ApJ 2003), “purely observation based”
(Vertical axis is just log(φ)/Mpc^3)

Model vs X-rays

- AGNs are likely sources of x-ray background
    - Existing models inadequate for high z and require ad hoc assumptions
- Thick lines are observations
        - Barcons et al 2000 and Gruber et all 1999
- Thin lines are predictions
    - Top and middle panel show model with different obscuration predictions
    - Bottom panel shows simpler models

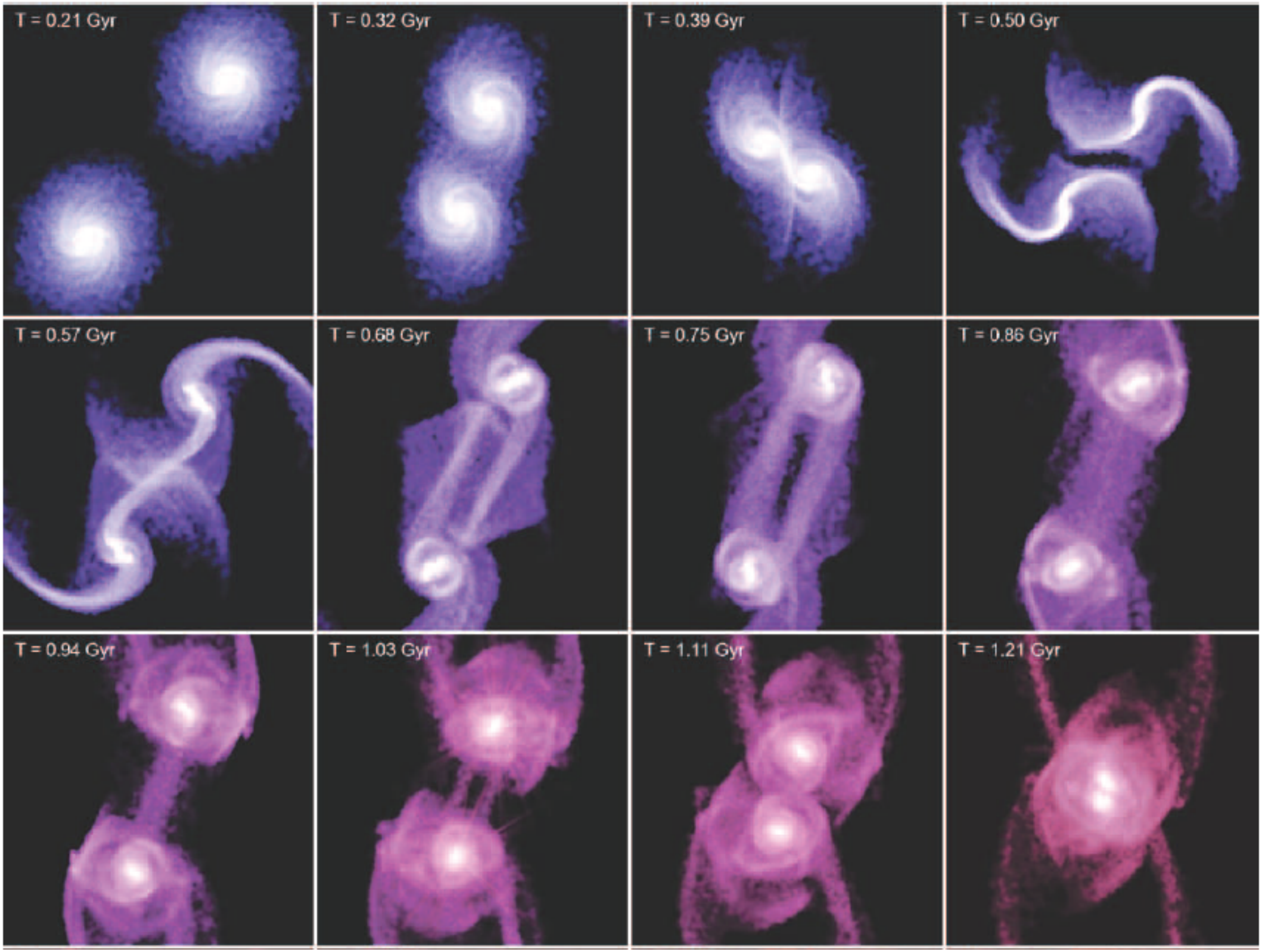


Additional Predictions & Tests

- Can use the model to predict
    - Column density distributions
    - Broad-line luminosity function and fraction
    - Active black hole mass function
    - Eddington ratios
    - Relic black hole mass function
    - Host galaxy properties
    - Gravitational wave signal from black hole mergers

Conclusions

- Supermassive black holes regulate galaxy formation and evolution via radiation
  - Mergers pull gas to center only to be expelled by quasars
  - Quasar lifetime well described as a function of L_{peak} and L
  - Previous models fail to successfully characterize the long low L tails of this lifetime
- $\dot{n}$ is poorly understood
  - Observations of black hole mass distribution probe faint end of $\dot{n}(L_{peak})$
  - Larger scale models should illuminate merger rates


T = 0.21 Gyr
T = 0.32 Gyr
T = 0.39 Gyr
T = 0.50 Gyr
T = 0.57 Gyr
T = 0.68 Gyr
T = 0.75 Gyr
T = 0.86 Gyr
T = 0.94 Gyr
T = 1.03 Gyr
T = 1.11 Gyr
T = 1.21 Gyr

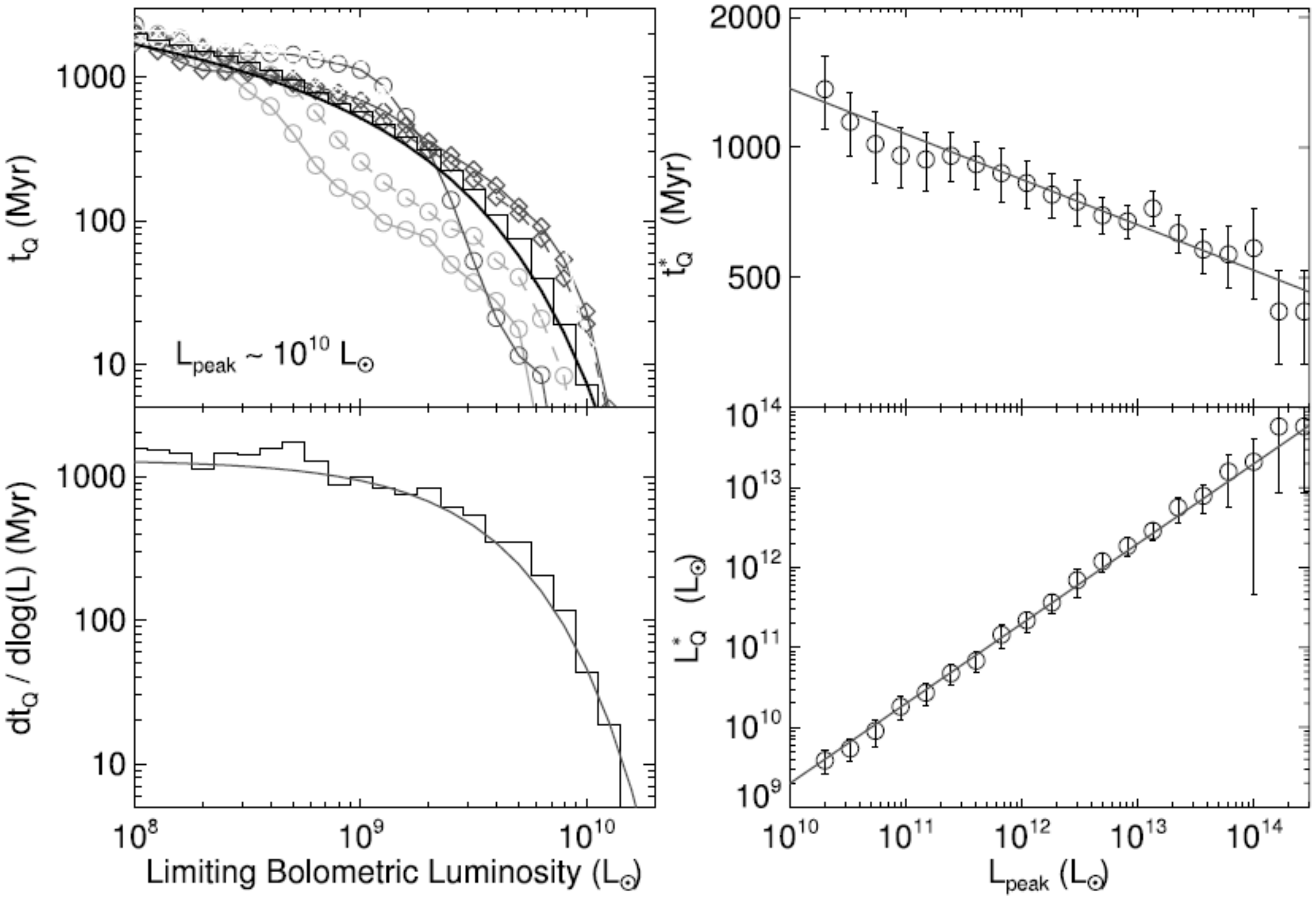
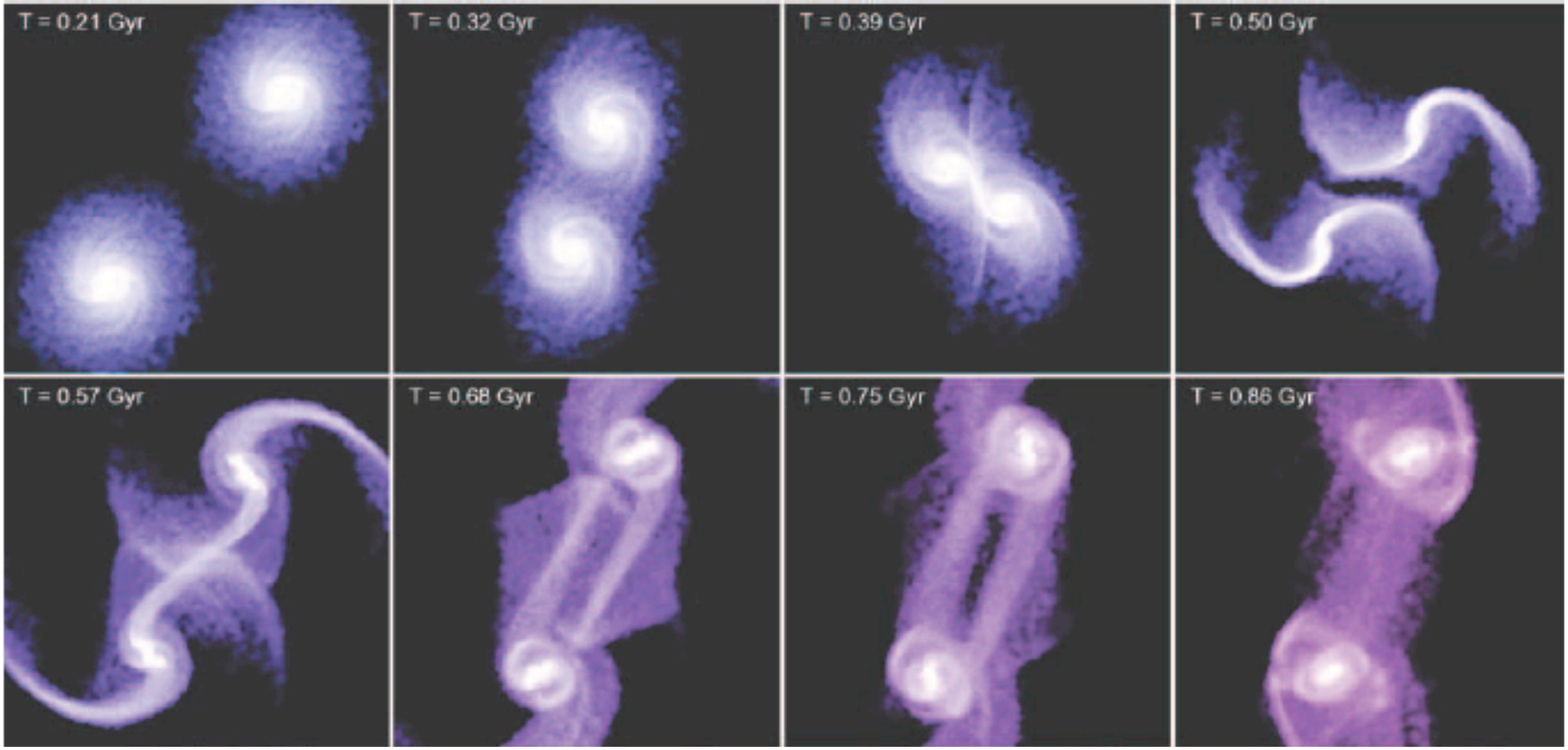
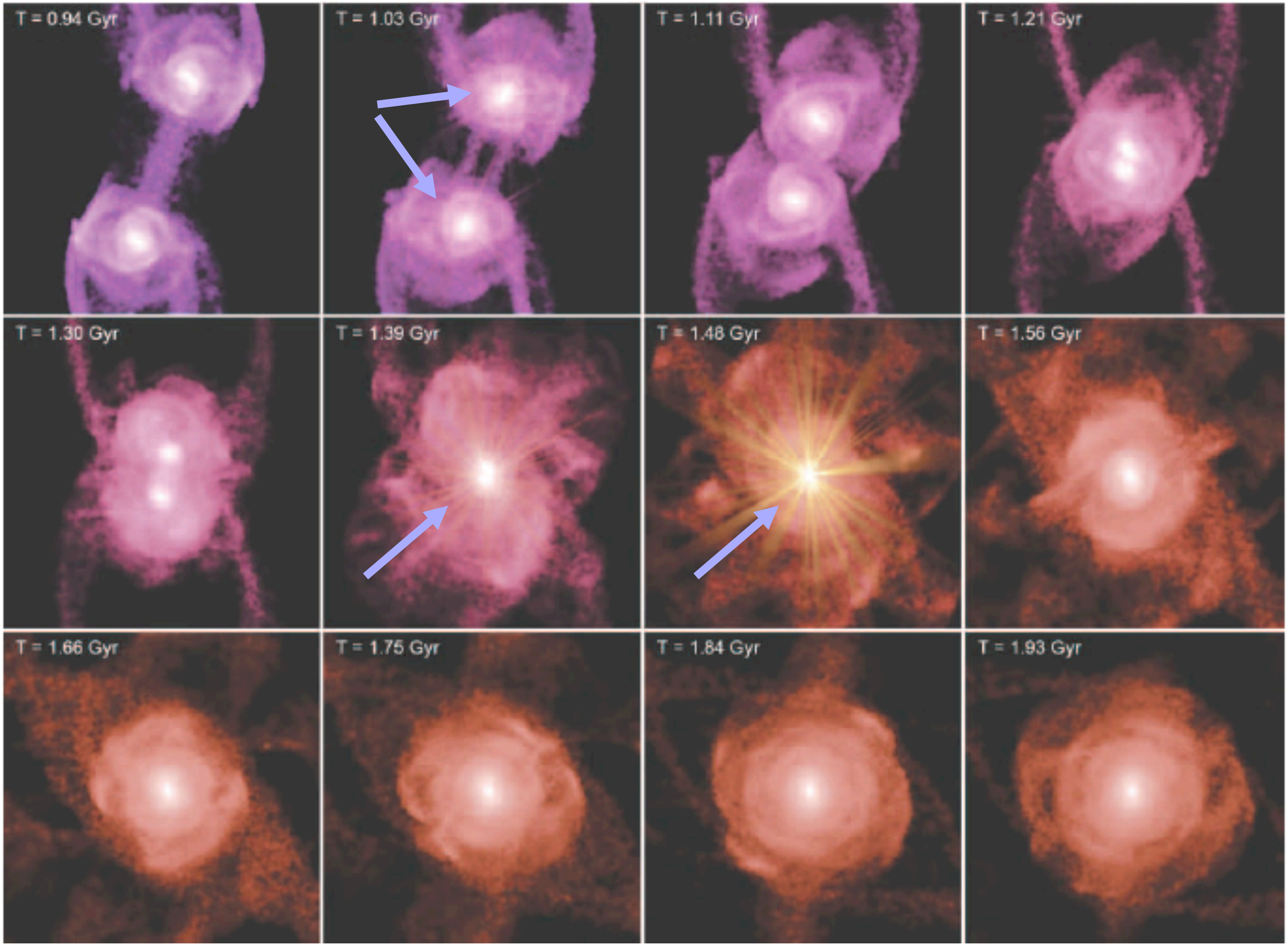


FIG. 5.—Fits to the quasar lifetime as a function of luminosity from our simulations. The top left panel shows the intrinsic, bolometric quasar lifetime t_Q of a set of simulations with $L_{\rm peak}$ within a factor of 2 of $10^{10}\ L_\odot$, in the manner of Fig. 4. The histogram shows the geometric mean of these lifetimes, and the histogram in the bottom left panel shows the differential lifetime $dt/d \log L$ from this geometric mean. The thick solid line in the top left panel and solid line in the bottom left panel show the best-fit to our analytical form, $dt/d \log L = t_Q^* \exp(-L/L_Q^*)$. The top right panel shows the fitted t_Q^* and resulting errors in each peak luminosity (final black hole mass) interval, and the best-fit power law to $t_Q^*(L_{\rm peak})$ (*solid line*). The bottom right panel shows the fitted L_Q^* and resulting errors in each peak luminosity (final black hole mass) interval, and the best-fit proportionality $L_Q^* \propto L_{\rm peak}$ (*solid line*). [*See the electronic edition of the Supplement for a color version of this figure.*]

Typical Merger




T = 0.94 Gyr
T = 1.03 Gyr
T = 1.11 Gyr
T = 1.21 Gyr
T = 1.30 Gyr
T = 1.39 Gyr
T = 1.48 Gyr
T = 1.56 Gyr
T = 1.66 Gyr
T = 1.75 Gyr
T = 1.84 Gyr
T = 1.93 Gyr