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Citation

Hopkins, Philip F., Lars Hernquist, Thomas J. Cox, Tiziana Di Matteo, Brant Robertson, and Volker Springel. 2005. "Luminosity-dependent Quasar Lifetimes: A New Interpretation of the Quasar Luminosity Function." *The Astrophysical Journal* 630 (2): 716–20. <https://doi.org/10.1086/432463>.

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LUMINOSITY-DEPENDENT QUASAR LIFETIMES: A NEW INTERPRETATION OF THE QUASAR LUMINOSITY FUNCTION

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ApJ, Accepted, September 2005

ABSTRACT

We propose a new interpretation of the quasar luminosity function (LF), derived from physically motivated models of quasar lifetimes and light curves. In our picture, quasars evolve rapidly and their lifetime depends on both their instantaneous *and* peak luminosities. We study this model using simulations of galaxy mergers that successfully reproduce a wide range of observed quasar phenomena. With lifetimes inferred from the simulations, we deconvolve the observed quasar LF from the distribution of peak luminosities, and show that they differ qualitatively, unlike for the simple models of quasar lifetimes used previously. We find that the bright end of the LF traces the intrinsic peak quasar activity, but that the faint end consists of quasars which are either undergoing exponential growth to much larger masses and higher luminosities, or are in sub-Eddington quiescent states going into or coming out of a period of peak activity. The “break” in the LF corresponds directly to the maximum in the intrinsic distribution of peak luminosities, which falls off at both brighter and fainter luminosities. Our interpretation of the quasar LF provides a physical basis for the nature and slope of the faint-end distribution, as well as the location of the break luminosity.

Subject headings: quasars: general — galaxies: nuclei — galaxies: active — galaxies: evolution — cosmology: theory

1. INTRODUCTION

The luminosity function (LF) of quasars is fundamental to cosmology, but even after more than 30 years of study (e.g., Schmidt 1968; Schmidt & Green 1983; Hartwick & Schade 1990; Warren et al. 1994; Boyle et al. 2000; Ueda et al. 2003), its relation to the intrinsic luminosities of quasars remains poorly understood. Previous work modeling the quasar LF has relied on restrictive assumptions about lifetimes and light curves of quasars, imagining, for example, that quasars either have universal lifetimes or that they evolve exponentially, usually on the galaxy dynamical time or the *e*-folding time for Eddington-limited black hole growth $t_S = M_{\text{BH}}/\dot{M} = 4 \times 10^8 \epsilon_r \text{ yr}$ for accretion with radiative efficiency $\epsilon_r = L/\dot{M}c^2 \sim 0.1$ (Salpeter 1964). Under these circumstances, the distribution of quasars with a given mass or peak luminosity is trivially related to the observed LF (in the absence of selection effects), and the two have essentially identical shape.

Recently, simulations of galaxy mergers incorporating black hole growth and feedback (Springel et al. 2005b) have reproduced the $M_{\text{BH}} - \sigma$ relation between black hole mass and galaxy velocity dispersion (Di Matteo et al. 2005) and linked quasar activity (Hopkins et al. 2005a,b) to galaxy evolution (Springel et al. 2005a). The simulations predict more complicated quasar light curves than have been adopted previously. The peak, exponential black hole growth phase is determined by the gas supply over timescales $\sim 10^8 \text{ yr}$ and shuts down when significant gas is expelled by feedback. The light curves have been studied by Hopkins et al. (2005a,b), who showed that the self-termination process gives observable lifetimes $\sim 10^7 \text{ yr}$ for bright optical quasars, in good agreement with observations, and yields a large population

of obscured sources as a natural stage of quasar evolution. Hopkins et al. (2005b) analyzed simulations over a range of galaxy masses and found that the quasar light curves and lifetimes are always qualitatively similar, with both the intrinsic and observed quasar lifetimes being strongly decreasing functions of luminosity, with longer lifetimes at all luminosities for higher-mass (higher peak luminosity) systems.

Here, we use our quasar lifetimes and light curves to deconvolve the observed quasar LF from the distribution of peak luminosities, and find that they differ qualitatively, unlike for the trivial light curves or even complex, cosmologically evolving light curves or distributions of Eddington ratios that have been employed previously, demanding a new interpretation of the quasar LF.

2. MODELING QUASAR LIFETIMES & LIGHT CURVES

Up to now, theoretical studies of the quasar LF have generally employed very simple descriptions of the quasar light curve, namely some variant of a “feast or famine” or “light bulb” model (e.g., Small & Blandford 1992; Kauffmann & Haehnelt 2000; Wyithe & Loeb 2003; Haiman, Quataert, & Bower 2004), in which quasars have only two states: “on” or “off.” When “on,” quasars have a constant luminosity and radiate at a characteristic Eddington ratio $l \equiv \langle L/L_{\text{Edd}} \rangle$, generally in the range $\sim 0.1 - 1$. This state is assumed to last for a universal lifetime $t_{Q, \text{LB}}$, which is the same for all quasars at a given redshift (although some models allow for redshift evolution of $t_{Q, \text{LB}}$). The value of $t_{Q, \text{LB}}$ is an input parameter of the models, generally adopted from observations or assumed to be related to the Salpeter time or the dynamical time of the host galaxy. The time spent in a logarithmic luminosity interval is then just $dt/d \log(L) = t_{Q, \text{LB}} \ln(10) L \delta(L - l L_{\text{Edd}})$. Although this approach is analytically simple, with the trivial light curve

$$f(t) = l L_{\text{Edd}} \Theta(t) \Theta(t_{Q, \text{LB}} - t), \quad (1)$$

where Θ is the Heaviside step function, it has no strong theoretical or observational motivation. For present purposes, models where quasars live arbitrarily long with

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slowly evolving mean volume emissivity or mean light curve (e.g. Small & Blandford 1992; Haiman & Menou 2000; Kauffmann & Haehnelt 2000) are equivalent to the “light bulb” scenario, as they still assume that quasars observed at a luminosity L radiate at that approximately constant luminosity over some universal lifetime $t_{Q,LB}$ at a particular redshift.

We also consider a variant of the “light bulb” scenario, which we term the “Eddington limited” model, where a black hole accretes at a fixed Eddington ratio l from an initial mass M_i to a final mass M_f (or equivalently, a final luminosity $L_f = lL_{Edd}(M_f)$), and then shuts off. This gives exponential mass and luminosity growth, with the light curve

$$f(t) = lL_{Edd}(M_i)e^{t/t_s}, \quad (2)$$

where $f(t) = 0$ for $t > \ln M_f/M_i$. The time spent in any logarithmic luminosity bin is constant,

$$dt/d\log(L) = t_s(\ln(10)/l) \quad (3)$$

for $L_i < L < L_f$. This is true for any exponential light curve $f(t) \propto e^{\pm t/t_s}$, such as that of Haiman & Loeb (1998), with only the normalization $dt/d\log(L) = t_*$ changed, and thus any such model will give identical results with correspondingly different normalizations. While such a light curve allows the black hole mass and luminosity to change, there is no theoretical expectation that black hole growth is well-approximated by a constant Eddington ratio.

We compare these scenarios to a physically motivated model using quasar lifetimes derived from simulated galaxy mergers (Hopkins et al. 2005a,b). The light curves from the simulations are complex, generally having periods of rapid accretion after “first passage” of the galaxies, followed by an extended quiescent period, then a transition to a peak, highly luminous quasar phase, and then a dimming as self-regulated mechanisms expel gas from the remnant center after the black hole reaches a critical mass (Di Matteo et al. 2005). In addition, the accretion rate at any time can be variable over small timescales $\sim \text{Myr}$, but even with these complexities, the statistical nature of the light curve can be described by simple forms. Hopkins et al. (2005b) find that the total quasar lifetime $t_Q(L' > L)$ above a given luminosity L is well-approximated by a truncated power law, with

$$t_Q(L' > L) = t_9(L/10^9 L_\odot)^\alpha, \quad (4)$$

where $t_9 \equiv t_Q(L' > 10^9 L_\odot) \sim 10^9 \text{ yr}$, over the range $10^9 L_\odot < L < L_{peak}$ for a given quasar. L_{peak} is, as above, determined by the final black hole mass, $L_{peak} \approx L_{Edd}(M_f)$. Over a wide range of L_{peak} (from $\sim 10^{10} - 10^{14} L_\odot$), Hopkins et al. (2005b) also find that α is a function of M_f (or L_{peak}), given by $\alpha = \alpha_0 + \alpha' \log L_{peak}$, with $\alpha = -0.2$ (the approximate slope of the Eddington-limited case) as an upper limit. This reflects the fact that larger quasars have shallower slopes as they spend more time at higher luminosities up to some larger peak luminosity. The time spent in any logarithmic luminosity interval in this range is then simply

$$dt/d\log(L) = |\alpha| t_9 (L/10^9 L_\odot)^\alpha. \quad (5)$$

In our picture, quasars spend far more time at low luminosities than at their peaks. This is a consequence of both pure $l = 1$ Eddington-limited growth up to a final black hole mass as well as a “brightening” and “dimming” out of and into extended quiescent phases of black hole growth around the peak quasar phase, during which the Eddington ratio changes with

FIG. 1.— A typical quasar light curve (top) and lifetime as a function of luminosity (bottom), for a major merger of Milky Way-like galaxies with a final black hole mass $M_f = 3 \times 10^8 M_\odot$ (Hopkins et al. 2005a). The simulation lifetime (solid line) is compared to the expected Eddington-limit model lifetime (dotted), the power law approximated lifetime (dashed), and the mixed power law-Eddington model (dash-dot), from the formulae in §2.

time in the range $l \sim 0.01 - 1$. We also consider a more complicated fit described in Hopkins et al. (2005b), where quasar lifetimes follow the Eddington-limited model at the brightest luminosities, down to some L_* , below which they are described by a power law. In all these cases, the best-fit break luminosity is a nearly constant fraction of the peak luminosity $L_* \approx 0.14 L_{peak}$. These fits have the advantage of being accurate at both low and high luminosities, down to lifetimes $\lesssim \text{Myr}$. In Figure 1, we show an example of the light curve from one of our simulations (top) and the relation between the lifetime and luminosity and various fits to it (bottom).

Our model contrasts sharply with both the “light bulb” and “Eddington limited” cases. The “light bulb” scenario ignores the evolution of the quasar as it accretes, and neglects the vast majority of its life at luminosities below its final peak. The “Eddington limited” model may be a reasonable approximation during the bright quasar phase near the final peak luminosity, but it underestimates the time spent at luminosities $L \lesssim 0.1 L_{peak}$ by as much as two orders of magnitude (Hopkins et al. 2005b). Furthermore, in our model, quasars can evolve significantly on short timescales ($\sim 10 \text{ Myr}$), which means that our interpretation yields a statistical mix of contributions from different peak luminosities and Eddington ratios at any observed luminosity at a given redshift, which contrasts strongly with any model in which the quasar light curve or emissivity evolves over cosmic time. We note that our arguments do not in any way depend on the obscuration model described in Hopkins et al. (2005a,b), as we consider only low enough redshifts that quasar LFs should be reasonably complete and therefore only “intrinsic” quasar lifetimes are relevant. Incorporating such effects, however, does not qualitatively change our conclusions. Moreover, the simulations from which we derive our lifetimes cover the complete range of intrinsic and observed luminosities of the LFs considered here, and show smoothly-changing properties in good agreement with the fits described above for all simulations in this range.

3. RESULTS

FIG. 2.— Deconvolved intrinsic distributions of peak luminosities $\dot{n}(L_{\text{peak}})$, from fitting to the Boyle et al. (2000) LF (diamonds) at redshift $z = 0.5$. Upper panel shows the fitted LF, lower panel the $\dot{n}(L_{\text{peak}})$ distribution for “light bulb” models (dashed), “Eddington limited” models (dotted), and luminosity dependent lifetimes fitted to power laws (thin) and fitted to combined power laws and Eddington growth (thick).

Given quasar lifetimes as functions of luminosity and peak luminosity, the LF is a convolution of the lifetime with the intrinsic distribution of sources with a given L_{peak} ,

$$\Phi(L) \propto \int \frac{dt(L, L_{\text{peak}})}{d \log(L)} \dot{n}(L_{\text{peak}}) d \log(L_{\text{peak}}). \quad (6)$$

Here, $\dot{n}(L_{\text{peak}})$ is the rate at which sources in a logarithmic interval in L_{peak} are created or “activated” per unit volume at some redshift, and $\Phi(L)$ is the observed number density of sources per logarithmic interval in L . This formulation implicitly accounts for the “duty cycle” (the fraction of active quasars at a given time), which is proportional to the lifetime at a given luminosity. As we do not attempt to model the number of halos containing quasars and wish to consider wide classes of lifetime models (which may have different normalizations), we do not concern ourselves with the absolute normalization of $\Phi(L)$ or $\dot{n}(L_{\text{peak}})$.

For the “light bulb” and “Eddington limited” scenarios respectively, this convolution and the corresponding deconvolution are trivial, giving

$$\dot{n}_{\text{LB}}(L_{\text{peak}}) \propto \Phi(L = L_{\text{peak}}) \quad (7)$$

$$\dot{n}_{\text{EL}}(L_{\text{peak}}) \propto \left. \frac{d\Phi}{d \log(L)} \right|_{L=L_{\text{peak}}} \quad (8)$$

for the intrinsic L_{peak} distributions. Steed & Weinberg (2003) use a similar method to de-convolve the distribution of sources and consider in detail a very wide range of models for the quasar light curve and distribution of Eddington ratios, but none of the models they consider include the fundamentally important feature of the lifetime increasing with decreasing luminosity to the lowest observed quasar luminosities, and further they do not allow the Eddington ratio distribution to depend on final black hole mass. As a result, every example in the range of models they consider, as well as those in previous works, results in an $\dot{n}(L_{\text{peak}})$ distribution qualitatively similar to the observed LF, increasing monotonically to lower luminosities (in the absence of an arbitrary truncation). However, in the case of our luminosity-dependent lifetimes, we must solve numerically for n_{LDL} , fitting to a given LF, and find a fundamentally different result.

Figure 2 shows the best-fit $\dot{n}(L_{\text{peak}})$ distributions for the above cases fitted to the Boyle et al. (2000) optical quasar

LF at redshift $z = 0.5$, as well as the best-fit LF. For luminosity-dependent lifetimes, we take a power law dependence on L_{peak} from Hopkins et al. (2005b), with $\alpha = -0.95 + 0.32 \log(L_{\text{peak}}/10^{12} L_{\odot})$ for pure truncated power-law fits and $\alpha = -0.98 + 0.32 \log(L_{\text{peak}}/10^{12} L_{\odot})$ for fits with a power-law mapped onto an Eddington-limited fit at near-peak luminosities. For ease of comparison with black hole mass and Eddington ratios, we rescale all B-band quantities to the bolometric luminosity using the corrections of Marconi et al. (2004). In all cases, it is possible to reproduce the double-power law LF and “break” luminosity L_{brk} quite accurately, and the $\dot{n}(L_{\text{peak}})$ distributions are similar at luminosities above L_{brk} . However, below L_{brk} , a proper accounting of the luminosity dependence of quasar lifetimes results in a radically different $\dot{n}(L_{\text{peak}})$ distribution, with the shallow slope of the LF a direct reflection of the slope in the lifetime vs. luminosity relation, dominated by quasars at the peak of the $\dot{n}(L_{\text{peak}})$ distribution, which then determines the “break” luminosity of the observed LF, with $L(n_{\text{LDL}, \text{max}}) \sim L_{\text{brk}}$. Note that the steepness of the $\dot{n}(L_{\text{peak}})$ cutoff is an artifact of extrapolating the LF to luminosities well below those observed – any strong decline below L_{brk} gives an equivalent fit to the actual data.

It is possible that objects which have already undergone a quasar phase may re-activate, or that black holes may already be very large when AGN activity first begins. To determine whether or not this changes our results, we consider the most extreme possible case, in which we return to the simulations of Hopkins et al. (2005a,b) and re-fit the quasar lifetimes but ignore all black hole activity prior to the final merger. This neglects all early accretion activity as black holes build up to a significant mass, as well as weaker, sub-Eddington accretion during the merger as gravitational torques from early merger stages funnel gas to the galaxy centers. Therefore, we expect this case to set a strong lower limit to the lifetime at low luminosities, regardless of the mechanism driving quasar activity. However, we still find that these lifetimes are well above the Eddington-limited model expectations, albeit with shallower best fit power law slopes $\alpha = -0.77 + 0.30 \log(L_{\text{peak}}/10^{12} L_{\odot})$ and a slightly lower (constant) normalization.

It has also been argued from observations of stellar black hole binaries that a transition between accretion states occurs at a critical Eddington ratio $\dot{m} \equiv \dot{M}/\dot{M}_{\text{Edd}}$, from radiatively inefficient accretion flows at low accretion rates (e.g., Esin, McClintock, & Narayan 1997) to radiatively efficient accretion through a standard Shakura & Sunyaev (1973) disk. Although the critical Eddington ratio for supermassive black holes is uncertain, observations of black hole binaries (Maccarone 2003) as well as theoretical extensions of accretion models (e.g., Meyer, Liu, & Meyer-Hofmeister 2000) suggest $\dot{m}_{\text{crit}} \sim 0.01$. We examine whether this can change our conclusions by re-fitting quasar lifetimes from our simulations. Because we assumed a constant radiative efficiency $L = \epsilon_r \dot{M} c^2$ with $\epsilon_r = 0.1$, we account for this effect by multiplying the simulation luminosity at all times by an additional “efficiency factor” f_{eff} which depends on the Eddington ratio $l = L/L_{\text{Edd}}$ (given an a priori constant assumed efficiency, $l = \dot{m}$ always),

$$f_{\text{eff}} = \begin{cases} 1 & \text{if } l > 0.01 \\ 100l & \text{if } l \leq 0.01. \end{cases} \quad (9)$$

This choice for the efficiency factor follows from ADAF models (Narayan & Yi 1995) and ensures that the radiative efficiency is continuous at the critical Eddington ratio $l_{\text{crit}} =$

FIG. 3. — As Figure 2, lower panel, but with lifetimes recalculated considering only times after the onset of peak quasar activity (thick), or decreasing the radiative efficiency below a critical Eddington ratio (thin). The dot-dashed line uses lifetimes calculated including both effects. “Light bulb” (dashed) and “Eddington limited” (dotted) models are shown for comparison. Triangles show the distribution of black hole masses expected from the distribution of early-type velocity dispersions (Sheth et al. 2003) and the $M_{BH} - \sigma$ relation from Tremaine et al. (2002).

0.01. We expect this to set an extreme limit to the impact of this transition, as we do not incorporate this effect dynamically in the simulations, which would slow “blowout” after the peak quasar phase and increase lifetimes at low luminosities. We again find that power-law lifetimes at low luminosities are much larger than the expectation from the Eddington-limited model, with best-fit slopes $\alpha = -0.94 + 0.33 \log(L_{peak}/10^{12} L_{\odot})$.

Figure 3 shows the best-fit $\dot{n}(L_{peak})$ distributions and LFs for these cases, in the manner of Figure 2. We also plot as an extreme limit the results obtained applying both the radiative efficiency correction above and considering only times during and after the final merger. This case gives the shallowest slopes, $\alpha = -0.50 + 0.5 \log(L_{peak}/10^{12} L_{\odot})$. Although the shallower slopes broaden the $\dot{n}(L_{peak})$ distribution, our results are qualitatively unchanged. We have further considered extreme cases such as making our original slopes shallower by 3σ , a factor ~ 2 , and find nearly identical results.

4. CONCLUSIONS

We consider realistic quasar light curves and lifetimes derived from hydrodynamical simulations of quasar activity, and find that this results in a qualitatively different form and evolution of the distribution in peak quasar luminosities $\dot{n}(L_{peak})$ (equivalently, final black hole masses or host system properties) than that derived or implied in previous works (e.g., Small & Blandford 1992; Haiman & Loeb 1998; Haiman & Menou 2000; Kauffmann & Haehnelt 2000; Wyithe & Loeb 2003; Volonteri et al. 2003; Haiman, Quataert, & Bower 2004). We describe the resulting new interpretation of the quasar luminosity function (LF) in which the steep bright-end consists of quasars radiating near their Eddington limits and is directly related to the distribution of intrinsic peak luminosities (or final black hole masses) as has been assumed previously. However, the shallow, faint-end of the LF describes black holes either growing efficiently in early stages of activity or in extended, quiescent states going into or coming out of a peak

bright quasar phase, with Eddington ratios generally between $l \sim 0.01$ and 1. These are not objects which were active at some earlier cosmic time and have since “shut down”, as are invoked in some “light bulb” models, but correspond to the evolution of quasars in mergers over short timescales and critically related (both physically and statistically) to the observed bright, Eddington-limited quasar phase. The “break” luminosity in the LF corresponds directly to the *peak* in the distribution of intrinsic quasar properties $\dot{n}(L_{peak})$. As such, observations of this break and its evolution present a powerful new probe of the quasar population.

We find that the observed quasar LF can be reproduced to high accuracy with a model of quasar lifetimes which depends on both the observed luminosity and peak luminosity of a quasar, for some distribution of peak luminosities $\dot{n}(L_{peak})$. We demonstrate this for the Boyle et al. (2000) LF at $z = 0.5$, but find identical qualitative results for the Miyaji et al. (2000) and Ueda et al. (2003) soft and hard X-ray LFs, over a wide range of redshifts $z = 0 - 3$. This is not trivial, as it is in the case of simpler models of quasar lifetimes (in which the $\dot{n}(L_{peak})$ distribution can be directly recovered from the LF). If the faint-end slope of the LF is too shallow, power-law luminosity dependent lifetimes will be too steep to reproduce it. If the faint-end slope is too steep, our lifetime model can reproduce the LF, but without a characteristic qualitative difference in behavior from “light bulb” or Eddington-limited models. In fact, it is a strong argument in favor of our picture that observed faint-end slopes lie just within the expected range, for any peaked population $\dot{n}(L_{peak})$.

Our new interpretation of the quasar LF immediately explains several other observations. The distribution of velocity dispersions in early-type systems (expected to have undergone merger-driven AGN activity) from Sheth et al. (2003) turns over and decreases below $\sigma \approx 160 \text{ km s}^{-1}$, which from the $M_{BH} - \sigma$ relation implies that the black hole mass distribution for remnants of major mergers of massive galaxies should turn over and decrease below $M_{BH} \sim 10^8 M_{\odot}$ ($L_{peak} \sim 10^{12} L_{\odot}$). Moreover, Haiman, Quataert, & Bower (2004) find that black holes with masses less than $\sim 10^7 M_{\odot}$ must be rare at high redshift to avoid significantly overpredicting the counts of bright radio sources. These observations are exactly as predicted by our deconvolution of the LF, where at high redshift $\dot{n}(L_{peak})$ is shifted to higher peak luminosity (black hole mass) and thus fewer low-mass black holes are produced. The $\dot{n}(L_{peak})$ distribution based on traditional models of quasar lifetimes, however, would necessarily predict that the vast majority of quasars, especially at high redshift where the number of quasars is larger, have final black hole masses well below this limit, with the number density increasing towards lower black hole masses. The shift of $\dot{n}(L_{peak})$ with time in our model can explain the entire observed range of the $z = 0$ black hole mass function (e.g., Marconi et al. 2004).

The distribution of observed Eddington ratios is also a natural consequence of our model, and does not invoke a particular probability distribution across sources to match observations. Quasars observed around and below the “break” in the LF (which dominate the total population) may be accreting at the Eddington rate, as they build up early in their lives, or may be in quiescent phases going into or out of their peak quasar activity. For these quiescent phases, both comparison of the lifetime power laws in §3 and direct calculation of the lifetime as a function of Eddington ratio (Hopkins et al. 2005a,b) show that they are dominated by relatively large Eddington

ratios $l \gtrsim 0.1$. Below $l \sim 0.01$, quasars at the peak of the $\dot{n}(L_{peak})$ distribution will be below limits measured in most surveys. Therefore, we expect a distribution of Eddington ratios concentrated between $l \sim 0.1 - 1$, with a small tail down to $l \sim 0.01$ and mean Eddington ratios increasing with luminosity, exactly as observed (Vestergaard 2004).

The sharp contrast between the intrinsic distribution of peak quasar luminosities and the observed LF provides clean and elegant tests of our theory. In our interpretation, the bright and faint ends of the LF correspond statistically to similar mixes of galaxies, but in various stages of evolution. However, in all other competing scenarios, the quasar luminosity is directly related to the mass of the host galaxy. Therefore, any observational probe that differentiates quasars based on their host galaxy properties such as, for example, the dependence of clustering of quasars on luminosity, can be used to discriminate our picture from older models. Early evidence from both quasar-quasar (Croom et al. 2005) and quasar-galaxy (Adelberger & Steidel 2005) correlations support this picture and suggest that quasar hosts have a well-defined characteristic mass, exactly as predicted by our model with a peaked $\dot{n}(L_{peak})$ and in stark contrast to previous models in which $\dot{n}(L_{peak})$ continues to increase below the break in the luminosity function.

Our modeling of realistic quasar lifetimes and the resulting new $\dot{n}(L_{peak})$ distribution and interpretation of the quasar luminosity function have a wide range of implications. Theoretical predictions of the active and relic supermassive black

hole density and mass functions, the contribution of quasars to the X-ray and infrared background, the observed Eddington ratio distribution as a function of luminosity and redshift, the evolution of characteristic black hole masses and quasar host galaxy masses with redshift, quasar correlation functions and bias, the relation between quasar and starburst or luminous infrared galaxy luminosity functions, the role of quasars in reionization, the population of high-redshift radio sources, means to discriminate between pure density and pure luminosity evolution of quasar populations at very high redshift, and the distribution and evolution of quasar host properties all depend on this quantity and must be revised in this new model. Semi-analytical models and cosmological simulations have focused on reproducing $\dot{n}(L_{peak})$ distributions qualitatively similar to the observed LF based on idealized models of the quasar lifetime, but should instead attempt to reproduce the fundamentally different $\dot{n}(L_{peak})$ distribution implied by our realistic, physically motivated models of the quasar light curve and luminosity-dependent quasar lifetimes.

This work was supported in part by NSF grants ACI 96-19019, AST 00-71019, AST 02-06299, and AST 03-07690, and NASA ATP grants NAG5-12140, NAG5-13292, and NAG5-13381. The simulations were performed at the Center for Parallel Astrophysical Computing at the Harvard-Smithsonian Center for Astrophysics.

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